Some Problems on Time Change of Gravity Part 1. On Effect of Oceanic Tides upon the Tidal Variation of Gravity

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Some Problems on Time Change of Gravity

Part 1. On Effect of Oceanic Tides upon the Tidal Variation of Gravity

and

Part 2. On Analytical Treatments for Data of the Tidal Variation of Gravity

By

Ichiro NAKAGAWA

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Part 1. On Effect of Oceanic Tides upon the Tidal Variation of Gravity

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Abstract

Recently observations of the tidal variation of gravity have come to be carried out frequently since completion of a highly sensitive gravimeter with automatic recording apparatus, and a great many of observations are being made at various regions of the world. But the values of tidal factor of gravity and phase lag obtained at many stations are not always identical. As to the cause of their diversity, it is suspected that the effects caused by oceanic tides, the local geological structure and the meteorological disturbances are probably responsible.

In the present article, results of a harmonic analysis based on the data obtained for 34 days at each of eleven stations in Japan by means of the Askania gravimeter No. 111 during a period of about two years from July 1957 to May 1959 (International Geophysical Year), and the effects of the oceanic tides and others upon the tidal variation of gravity are in detail discussed, and it has come to be established that the most reliable value of the tidal factor of gravity in Japan free from the influence of the oceanic tides, is 1.14 and that the phase lag is very small even if it exists.

1. Introduction

Change of gravity with time is generally divided into two branches. Namely, one is a periodic variation and the other non-periodic. The periodic variation of gravity is a phenomenon caused by the tide-generating forces due to the Sun and the Moon and its variation is regular. The periodic gravity variation of this kind is usually referred to as the 'tidal variation of gravity' On the other hand, the non-periodic change of gravity, if existing, is regarded to be related with rapid or gradual change of gravity caused by the change of state or motion of the underground material, the fluctuation of rotation speed of the earth, the crustal deformation and the like.

It has been noticed and disputed since the Newtonian age that the oceanic water shows a tidal motion due to the influence of a celestial body. But a theoretical investigation on earth tides, the tidal deformation of the earth itself, was commenced by Lord Kelvin in 1863 (**1**), generalized and greatly developed by A. E. H. Love in 1909 (**2**) and more in detail advanced, at present, by many succeeding researchers such as H. Takeuchi (**3**) and others.

Now, let the tide-generating potential at any point on the earth due to a celestial body be denotes by W_2. According to the theory, if the earth is perfectly rigid, the quantity Δg of the tidal variation of gravity at its point is expressed by

$$\Delta g=\left(\frac{\partial W_2}{\partial r}\right)_{r=a}, \tag{1.1}$$

where r is the radius vector from the earth centre and a the mean radius of the earth. However the real earth is a finite elastic body and consequently yields by action of the tide-generating force. Such being the case, the value Δg of the tidal variation of gravity on the real earth is

$$\Delta g=G\cdot\left(\frac{\partial W_2}{\partial r}\right)_{r=a}, \tag{1.2}$$

$$G\equiv 1-\frac{3}{2}k+h, \tag{1.3}$$

where h and k are dimensionless constants called "Love's numbers". h is related with the radial displacement of the earth's surface caused by deformation of the earth, and k the change of potential field caused by the same cause. Love's numbers, h and k, are closely correlated with the rigidity and density distributions within the earth. And the symbol G is usually called "tidal factor of gravity" or, in short, "gravimetric factor"

On the other hand, the value of D which is called "diminishing factor" can be obtained from a tiltmetric observation or observation of the oceanic tides. Diminishing factor D is expressed by the formula

$$D\equiv 1+k-h. \tag{1.4}$$

Consequently, if the values of G and D are determined from observations, the numerical values of Love's numbers, h and k, can easily be determined, without any assumption on the density and elasticity distributions of the earth's interior, by combining (1.3) with (1.4).

Since the first successful observation of earth tides with the tiltmeter of the horizontal pendulum type by E. von Rebeur-Paschwitz in 1892 (4), a great many tiltmetric observations on earth tides have been made at various places in the world. But, contrary to a tiltmetric observation, success of observation of earth tides with gravimeter has been exceedingly delayed mainly due to a technical difficulty of observation, because the quantity of its variation is extremely small.

Tidal variation of gravity was first observed with the gravimeter of the bifilar suspension type by W. Schweydar in 1914 (5). Since then, a great many observations have been made at many stations in the world and many fruitful results are reported. However the values of the tidal factor of gravity obtained by these observations show divergency of wide range from 0.8 to 1.3. Value of the tidal factor of gravity must in principle be equal wherever or whenever the observation be carried out. Consequently, it is naturally presumed that the values of the tidal factor of gravity obtained are considerably disturbed by certain effects. For the causes of such a diversity, the following may be considered, that is, the situation of the observation station, the effect of the oceanic tides, the influence of the local geological structure, the effect of meteorological disturbances, the difference of the instrument used, the difference in time of observation, the difference in length of observation periods, the methodical difference in treating the data, and others. A thorough investigation for those causes is an essential and attractive problem on the gravimetric study of earth tides.

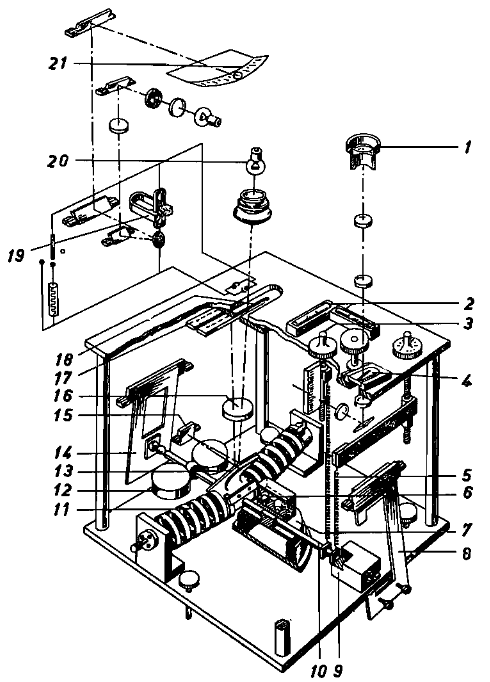
As described above, the tidal factor of gravity is available for investigation of the state of the earth's interior by combination with the diminishing factor. For that purpose, the disturbances originated by various causes must be excluded of the observed tidal factor of gravity. Furthermore, an accurate value of the tidal factor of gravity is required by those who are concerned with the gravimetric prospecting and survey. It will become, in future, more and more an important constant in various fields of geodesy.

In view of the above, a detailed study on these points will be made in a succeeding article. In the present article, the results obtained from observations of the tidal variation of gravity by means of the Askania gravimeter No. 111 at eleven stations in Japan are described. Based on such observational results, effects caused by various conditions of the station, particularly the action of the oceanic tides of neighbouring sea are in detail discussed, and the most reliable value of the tidal factor of gravity after the full corrections is obtained.

2. Observations

(1) Instrument

The instrument used in the present observations is Askania Gs-11 gravimeter No. 111, imported on the spring of 1957, and its construction schematically shown in Fig. 1.1 (**6**).



1. Eyepiece
2. Spirit cross level
3. Operating knob for the spindle and measuring spring
4. Micrometer with operating knob
5. Measuring range spring
6. Bronze ball of the calibrating mechanism
7. Damping bell
8. Arresting lever
9. Gravimeter mass
10. Lever arm
11. Gravimeter main spring
12. Buoyancy float
13. Suspension mirror
14. Arresting lever
15. Counter mirror
16. Objective lens
17. Differential photocell
18. Slit
19. Mirror galvanometer
20. Photocell illumination lamp
21. Galvanometer scale

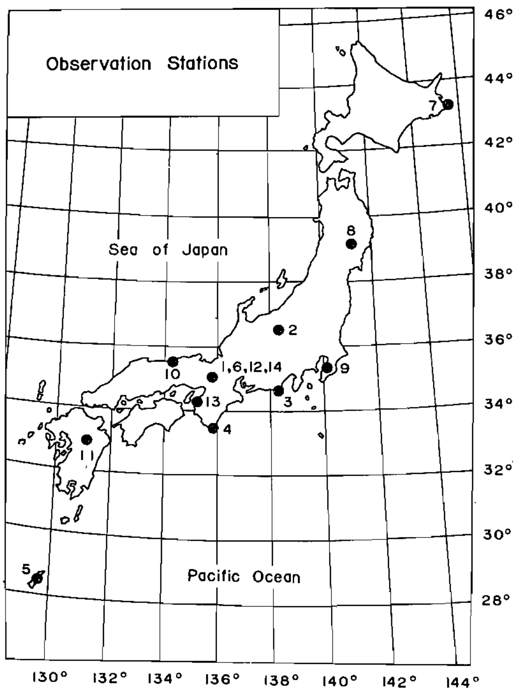
Fig. 1.1. Schematic representation of measuring system of an Askania gravimeter.

Pendulum part of the gravimeter is in a double thermostat which is operated by 6 volts D. C. and is in constant temperature with an accuracy of 0.01°C. The time change of gravity can be recorded continuously and automatically by connecting a recording galvanometer and photoelectric tracing recorder with the gravimeter. In this case, the method of measurement is not zero-method, but change in the inclination of mass lever arm of the gravimeter caused by gravity change is magnified by photoelectric circuit and recorded on the recording drum, its sensitivity being nearly 2.5 μgal/mm on the registrogram.

The scale constant of the Askania gravimeter is originally given by its manufactory, but on the other hand the bead device in itself is conveniently and supplementally available as a calibrating device for the scale constant. By using this device, the change of the scale constant can easily, promptly and precisely be measured.

(2) Observation stations

For the causes regarded to affect the tidal variation of gravity, various effects must be taken into consideration as already described in the previous section. Above all, the action of the oceanic tides and the difference of the local geological structure about the station have been taken as the most



1. Kyoto (I)
2. Matsushiro
3. Omaezaki
4. Shionomisaki
5. Naze
6. Kyoto (II)
7. Nemuro
8. Mizusawa
9. Kanozan
10. Tottori
11. Aso
12. Kyoto (II)
13. Wakayama
14. Kyoto (II)

Fig. 1.2. Positions of the earth tidal observation station with the Askania gravimeter No. 111.

Table 1.1. Description of the observation stations

Station number	Observation station	Remark
1	Kyoto (I)	Kyoto University, Geophysical Institute, Old building
2	Matsushiro	Seismological Observatory
3	Omaezaki	Omaezaki Weather Station
4	Shionomisaki	Shionomisaki Weather Station
5	Naze	Naze Weather Station
6	Kyoto (II)	Kyoto University, Geophysical Institute, New building
7	Nemuro	Nemuro Weather Station
8	Mizusawa	Mizusawa International Latitude Observatory
9	Kanozan	Kanozan Geodetic Observatory (Geographical Survey Institute)
10	Tottori	Tottori Scientific Museum
11	Aso	Aso Volcanological Laboratory (Kyoto University)

Station number	Location			g (gal)	Gravity anomaly (mgal)	Distance from the effective nearest sea (km)
	Latitude (N)	Longitude (E)	Height (m)			
1	35°02′	135°47′	57.8	979.722	− 14	50
2	36 32	138 13	434.0	979.784	− 10	170
3	34 36	138 13	45.5	979.755	+ 52	0.5
4	33 27	135 46	74.2	979.740	+ 139	0.4
5	28 23	129 30	3.3	979.312*	+ 100*	0.08
6	35 02	135 47	59.9	979.721	− 14	50
7	43 20	145 35	25.1	980.692	+ 222	0.7
8	39 08	141 08	60.7	980.160	+ 69	50
9	35 15	139 58	350.5	979.704	+ 6	9
10	35 30	134 14	20	979.801*	+ 17*	5
11	32 53	131 01	567	979.425*	− 16*	40

Station number	Thermostat setting (°C)	Date of calibration		Observation period
		At the start of observation	At the end of observation	
1	40	VI. 17, 1957	VIII. 2, 1957	VI. 28, 1957—VII. 31, 1957
2	40	VIII. 23, 1957	IX. 29, 1957	VIII. 25, 1957— IX. 27, 1957
3	40	X. 5, 1957	XI. 15, 1957	X. 8, 1957— XI. 10, 1957
4	35	I. 17, 1958	II. 23, 1958	I. 18, 1958— II. 20, 1958
5	40	III. 29, 1958	V. 7, 1958	III. 31, 1958— V. 3, 1958
6	40	VI. 10, 1958	VII. 15, 1958	VI. 11, 1958—VII. 14, 1958
7	40	VII. 31, 1958	IX. 5, 1958	VIII. 1, 1958— IX. 3, 1958
8	40	IX. 13, 1958	X. 20, 1958	IX. 15, 1958— X. 18, 1958
9	40	X. 29, 1958	XII. 3, 1958	X. 30, 1958—XII. 2, 1958
10	35	II. 6, 1959	III. 13, 1959	II. 7, 1959— III. 12, 1959
11	40	IV. 16, 1959	V. 23, 1959	IV. 18, 1959— V. 21, 1959

Notes The distance between Kyoto (I) and Kyoto (II) is about 300 metres.
The values with asterisk are tentatively assumed.

predominant factors among them. Therefore, in selecting an observation station, these conditions have taken primarily into account. Since the observation was made mainly during International Geophysical Year, the observation stations were selected so as to complete observation in nearly two years with the conditions above described. In order to investigate the effect of the oceanic tides, the observation stations were selected with due regard to the distance from the effective sea. Among the stations thus selected, a solitary island in the Pacific Ocean was included. As for the effect of the geological structure about the station, the observation stations were selected from the places located in positive and negative zones and near zero line respectively, referring to the map of Bouguer anomalies compiled by C. Tsuboi and others (7). Furthermore a few stations were selected in the volcanic region and seismically active area so as to investigate the relation between these phenomena and the gravity change.

The observation stations selected from this point of view are shown in Fig. 1.2. In the present article, the eleven stations, where gravimetric observations were carried out from July 1957 to May 1959, were selected for investigation. The location of these stations, the observation periods and others are shown in Table 1.1.

(3) Observations

Observations were carried out by automatic recording with a photoelectric tracing recorder. The ground or basement room isolated from other building as far as possible, was selected as observation room. The gravimeter and recorder were installed on the concrete block or the concrete floor of the room. The maximum daily variation of temperature in the present series of observation room reached 2°C but the daily amplitude of room temperature was, on an average, less than 1°C. The humidity in the room was about 70%. In particular, the observation at Kyoto (II) was carried out in a special room where the International Reference Station of Gravity in Japan and the temperature and humidity in this room were maintained by means of the thermostatically controlled apparatus throughout a year as 19.5°C±0.2°C and 55%±1% respectively.

Every observation of the tidal variation of gravity at each station was made during a period of 34 days. Before and after the observation at each station, the spindle scale constant of the gravimeter and the scale coefficient of recording were precisely calibrated. The gravimeter was always maintained in the best condition during the whole periods of observation.

All electric currents were stabilized with high accuracy and were in good connection with the earth. In particular, as the method of measurement in the present case of automatic recording was not zero-method, the electric power supply for the main lamp which illuminated the photocell was doubly stabilized and careful attention was given so as to maintain the sensitivity of the gravimeter in a constant state.

The speed of motion of the recording paper was 8 mm/hour and it was renewed once a day. Tidal variation of gravity was recorded as a wave with about 10–15 cm of the maximum amplitude on the recording paper. Time-marks were recorded at every hour by the clock which was connected with the circuit of the recording galvanometer and their accuracy was ± 30 seconds.

When there is no drift in gravimeter, the tidal variation of gravity can be recorded indefinitely without reset. But, in practice, as the spring of the gravimeter was flowed by the drift, the reset to return the light-mark of the galvanometer to the normal position, was necessary at a suitable time. Namely, the reset was usually made once or twice a week, but in case of favourable condition, it was made only once every 10–15 days.

3. Calibrations of the Askania gravimeter No. 111

(1) Results of calibration

In case of the gravity observation by means of a gravimeter, the fundamental element was found to be precise determination of scale constant. Its determination has been usually carried out in comparison with known gravity values at several base stations of gravity established by pendulums. Concerning an Askania gravimeter, the scale constant was given by the maker, but on the other hand the built-in calibrating device by ball displacement method, was intended to make possible checks on the scale constant of the gravimeter, a bronze ball of diameter of 2.5 mm moved along the mass lever arm with two bores (distance : 5 mm) on the beam (8).

Since the measuring system of an Askania gravimeter is controlled electrically, its accuracy in calibration and observation depends upon the electric conditions. As source of electricity, a stabilized one with highly precise accuracy was utilized. In particular, in case of the automatic recording of the gravity change by its gravimeter, the electric current supply for the main lamp which illuminated the photocell was doubly stabilized and its circuit was good connection with the earth because the method of measurement was not zero-method.

In the beginning of observation of the tidal variation of gravity at each station, the determination of the minima of sensitivity to inclination, the determination of zero-point of the photoelectric measuring system called "Battery Insensitive Point", and the calibration of the scale constants of the gravimeter and the recording, were carried out thoroughly and the best condition of the instruments was examined. The observation was operated by setting the gravimeter in this stage. These calibrations were again made after the observation at each station and it was checked whether the change of sensitivity of the instrument took place during the observation (**9**).

The values of the spindle scale a (spindle scale division) corresponding to ball displacement determined in the beginning and the end of observation at each station, are shown in Table 1.2.

According to the theory of an Askania gravimeter (**6**), the ball value E (mgal) at the place where the value of gravity is g (gal), is given by

Table 1.2. Values of spindle scale "a" corresponding to ball displacement (unit in spindle scale divisions)

Station number	At the start of observation		At the end of observation		Mean	
	Position of scale	Spindle displacement	Position of scale	Spindle displacement	Position of scale	Spindle displacement "a"
1	36.88	5.5190	37.08	5.5159	36.98	5.5175±0.0017
2	47.36	5.5099	47.33	5.5102	47.34^{5}	5.5101±0.0002
3	43.69	5.5157	43.76	5.5161	43.72^{5}	5.5159±0.0003
4	43.49	5.5035	43.50	5.5104	43.49^{5}	5.5069±0.0035
5	32.67	5.5117	32.82	5.5130	32.74^{5}	5.5123±0.0008
6	40.58	5.5114	40.62	5.5118	40.60	5.5116±0.0021
7	51.18	5.5128	51.32	5.5117	51.25	5.5123±0.0006
8	46.68	5.5100	46.78	5.5141	46.73	5.5121±0.0021
9	38.98	5.5144	38.96	5.5179	38.97	5.5161±0.0018
10	53.12	5.5226	53.12	5.5222	53.12	5.5224±0.0003
11	43.40	5.5079	43.48	5.5155	43.44	5.5117±0.0038

$$E=\frac{g}{g_0}\cdot E_0\,, \tag{1.5}$$

where E_0 is the ball value determined at the place where the value of gravity is g_0. The ball value of the Askania gravimeter No. 111 used in the present observations is given by the maker as follows (8) :

$$E_0=41.62\ \text{mgal} \qquad \text{for} \qquad g_0=981.280\ \text{gal}. \tag{1.6}$$

Therefore the ball value at each station can simply be computed by using (1.5), (1.6) and the value of g in Table 1.1.

Then, the spindle scale constant b (mgal/div.)……the value of gravity corresponding to one division on the spindle scale……of the gravimeter at each station will be computed by the following equation

$$b=\frac{E}{a} \tag{1.7}$$

The results thus obtained are tabulated in Table 1.3 with Askania firm's values.

Table 1.3. Spindle scale constant "b" determined by the method of bead displacement

Station number	Thermostat setting (°C)	Position of scale (scale div.)	Spindle scale constant b (mgal/div.)	Maker's value* b (mgal/div.)	Difference (%)
1	40	36.98	7.5313±0.0024	7.5328	0.020
2	40	47.34[5]	7.5420±0.0004	7.5366	0.072
3	40	43.72[5]	7.5337±0.0005	7.5354	0.023
4	35	43.49[5]	7.5460±0.0049	7.5352	0.143
5	40	32.74[5]	7.5344±0.0012	7.5313	0.041
6	40	40.60	7.5394±0.0030	7.5342	0.069
7	40	51.25	7.5459±0.0009	7.5381	0.103
8	40	46.73	7.5420±0.0030	7.5365	0.073
9	40	38.97	7.5330±0.0025	7.5336	0.008
10	35	53.12	7.5252±0.0005	7.5388	0.180
11	40	43.44	7.5369±0.0053	7.5352	0.023

* The value given by the maker for the same position of spindle.

And these results are also shown in Fig. 1.3. In Fig. 1.3, the solid line shows the straight line passing nine stations (except two stations of Shionomisaki and Tottori) determined by the least square method of the data obtained by the calibration, while the dotted line shows that of scale constant given by the maker.

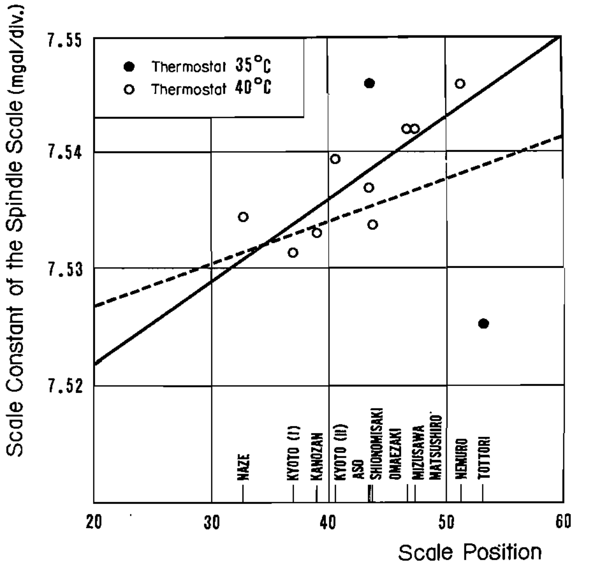


Fig. 1.3. The spindle scale constant of the Askania gravimeter No. 111.

Next, at beginning and end of each observation, the calibration of recording, as well as that of the spindle scale constant, was carried out by turning the spindle of the gravimeter, in suitable angle, several times every one or two hours. The corresponding shifts of the recording pencil on the registrograms were measured graphically by extrapolation and used for determining the scale constant of the recording, needless to mention that the displacement on the registrogram corresponding to the reset of the gravimeter spindle made in observation, was used for that determination.

The values of the scale coefficient of recording R(mm/0.01 div.)······ the displacement on the registrogram corresponding to 0.01 division of the spindle scale······determined at each station are shown in Table 1.4. No

Table 1.4. Scale coefficient of recording "R"

Station number	Number of shift	Scale coefficient of recording R (mm/0.01 div.)	Error (%)
1	28	28.946±0.240	± 0.83
2	18	29.258±0.195	± 0.67
3	31	30.399±0.188	± 0.62
4	17	30.007±0.320	± 1.07
5	30	30.025±0.237	± 0.79
6	12	29.853±0.216	± 0.72
7	19	27.130±0.227	± 0.84
8	23	27.888±0.251	± 0.90
9	28	27.503±0.353	± 1.28
10	28	23.879±0.307	± 1.29
11	29	29.498±0.199	± 0.67

changes in the scale of the recording were found during each observation.

Due to a large inertia of the whole circuit of the recording galvanometer, even after small and quick change in the tension of the measuring spring, considerable time was necessary for the galvanometer light-mark to get the new equilibrium position. This considerably reduced the accuracy of determination of the scale coefficient of recording.

As mentioned above, the values of the spindle scale constant given in Table 1.3 were the results for the spindle position in calibration. Then, by transforming these into results for the mean position of the spindle scale which was made in the gravimetric tidal observation, Table 1.5 was obtained.

Table 1.5. The final scale constant corrected for the difference of the spindle scale positions used in cases of calibration and observation

Station number	Position of scale* (scale div.)	Spindle scale constant** b (mgal/div.)	Maker's value*** b (mgal/div.)
1	34.197	7.5293	7.5318
2	44.543	7.5400	7.5356
3	40.964	7.5317	7.5343
4	40.798	7.5441	7.5343
5	29.951	7.5324	7.5303
6	37.850	7.5374	7.5332
7	48.528	7.5439	7.5371
8	43.954	7.5400	7.5354
9	36.203	7.5311	7.5326
10	50.331	7.5232	7.5378
11	40.701	7.5349	7.5342

* Mean position of spindle scale in observation.
** Corrected spindle scale constant.
*** Spindle scale constant given by the maker.

Now, using b and R, the scale constant of recording $S(\mu\text{gal/mm})$······ the number of microgals corresponding to one millimetre of recording······ is expressed by

$$S=10\cdot\frac{b}{R}\,. \tag{1.8}$$

The values of the scale constant of recording for each station deduced from the values given in Tables 1.4 and 1.5, are shown in Table 1.6. In further treatment of the observational data, the values of S shown in this

Table 1.6. Scale constant of recording "S"

Station number	Scale constant of recording* S (μgal/mm)	Maker's value** S (μgal/mm)	Difference (%)
1	2.6012 ± 0.0217	2.6020	0.031
2	2.5771 ± 0.0173	2.5756	0.058
3	2.4776 ± 0.0154	2.4785	0.036
4	2.5141 ± 0.0269	2.5108	0.131
5	2.5087 ± 0.0199	2.5080	0.028
6	2.5248 ± 0.0184	2.5234	0.055
7	2.7806 ± 0.0234	2.7781	0.090
8	2.7037 ± 0.0244	2.7020	0.063
9	2.7383 ± 0.0353	2.7388	0.018
10	3.1506 ± 0.0406	3.1567	0.193
11	2.5544 ± 0.0174	2.5541	0.012

* The value deduced from the spindle scale constant obtained by the calibration.
** The value deduced from the spindle scale constant given by the maker.

table are used.

(2) A few thoughts

As can be seen from the Table 1.3, the ratio of difference to original value between the spindle scale constant of the Askania gravimeter No. 111 determined by the bead displacement method, by the author, at each station and that given by the Askania firm for the same position of the spindle, was within 0.1%. The determination of the scale constant by the maker, was made at 40°C in the thermostat. The author's calibrations were made at almost all of the observation stations at the same temperature of 40°C in the thermostat as the maker's. But the calibration and observation at two stations of Shionomisaki and Tottori were made at 35°C because they were made in winter. In these two stations, the difference between the scale constant determined by the calibration and that given by the maker exceeded 0.1%, but was less than 0.2%.

Discussions concerning calibration of an Askania gravimeter were recently reported by Moscow researchers (**10**, **11**, **12**, **13**). According to their reports, it was concluded that the spindle scale constant determined by the bead displacement method was in good agreement with that given by the maker within 0.2%. This is of the same order of the conclusion as obtained by the author.

In Table 1.4, there was no systematic difference in observational error at each station. But the values of the scale coefficient of recording at Nemuro, Mizusawa, Kanozan and Tottori differed considerably from those of the other stations. The causes regarded that at the former three stations were the regions where the source of electricity was 50 c/s, while the others 60 c/s, and that the sensitivity of recording was reduced at Tottori because of violent meteorological disturbances. In all cases, the accuracy for the determination of the scale coefficient of recording was about 1%. Concerning the problem on the calibration of recording, B. P. Pertsev (**14**) devised two methods for determining the scale coefficient of recording. J. S. Dobrokhotov and others (**12**) computed the scale coefficient of recording by applying both of extrapolation and Pertsev's method to the observational data at Pulkovo. According to their results, the accuracies of the determination by both methods were 2% and 1% respectively and the value of the scale coefficient of recording computed by the former was about 2% less than that of the latter, they being the noticeable results.

Moreover, N. N. Pariisky and others (**13**) reported that the scale of galvanometer of the Askania gravimeter No. 134 was not linear and accordingly the correction for non-linearity reached 5-7% in the ordinates relative to the zero-line of the galvanometer. By good luck, there was no non-linearity in the scale of the galvanometer used by the author and no changes in the scale coefficient of recording, were found during observation at every station.

Generally speaking, the accuracy for determination of the scale constant of recording was nearly 1%. As already mentioned above, due to a large inertia of the whole circuit of the recording galvanometer, even after small and quick change in the tension of the measuring spring, the light-mark reached a new equilibrium position some 30-60 minutes after turn of the spindle. From this fact, when one would discuss the earth tides based on the data read from the registrograms, one presumed that the instrumental lag to be, of course, included on the phases of the diurnal and semi-diurnal waves of the tides. This point must be the subject of a future research.

Problem concerning the calibrations of gravimeter was very important in precise study of gravity change. In the present case, a fairly good agreement with the accuracy of 0.1% was fortunately found between the scale constant of the Askania gravimeter No. 111 obtained by calibration at each station and that as given by the maker. Consequently the same result could be obtained practically whenever either of them was applied. In the following, the value of scale constant determined by calibration was solely used in treatment of the observed data.

4. Observational results

(1) Reading from the registrograms

In spite of a highly precise stabilization of the electric current and good connection of the circuit with the earth, the recordings of the tidal variation of gravity were not always a smoothed curve and showed sometimes irregular jumps and disturbances. Among them, some returned naturally to the normal position, while others did not return.

Several causes were examined for the irregular appearance of recorded curve in the registrogram. The causes of such disturbances on the record were considered as follows :

a. Electric disturbance on the measuring system.
b. Apparent change caused by instrumental error.
c. Effect caused by change of the meteorological and other disturbing factors.
d. Real change of gravity.

If the disturbances on the record were representation of the real change of gravity, they must be closely connected with the crustal movement of a large scale, or free oscillations of the earth and other phenomena, and their thorough investigation called for as great importance.

To what extent such jumps and disturbances on the record affected the analytical results, must be known so as to analyse correctly the observed data. As for this problem, there were researches by M. S. Reford (**15**), and N. N. Pariisky and others (**11**). They showed that it was necessary to exclude thoroughly such jumps on the registrogram. N. N. Pariisky and others (**11**) gave also a thought to the effect upon the analytical results due to misreading of the registrogram, and pointed out that there was considerably large influence, although it was not so severe as jump.

Readings of the registrograms were practically made by the following method. If jump or disturbance returned naturally to the normal position, the readings were graphically interpolated by drawing a smoothed curve. And, if there was no return, the discontinuities were carefully excluded. In other cases, the readings were made as faithfully as possible. Readings from the registrograms were carried out twice independently at every hour up to 0.1 mm (about 0.25 μgal in gravity difference) and its mean value was adopted as datum. In readings, attention was given so as to exclude individual errors.

Interruption of the data was inevitable in the practical observation. Almost all of the causes were stoppage of electric current, but some were earthquakes. But, as it was not continued for more than several hours, by good luck, in almost all cases, its part was interpolated in due consideration of the recordings around that period and the theoretical tidal curve synthesised by the tide-predictor in the corresponding period. Such methods of interpolation were recently reported by I. M. Longman (**16**, **17**), A. P. Venedikov (**18**) and R. Lecolazet (**19**), all similar to the method used by the author.

In order to investigate the degree of confidence of the data, it was found effective to compare the analytical results obtained from the observational data on every hour with those of every 30 minutes in the same period. Concerning this problem, some researchers had taken interest. For example, according to the study by R. Tomaschek (**20**, **21**), he reported that there were differences of 1% at the largest in tidal factor of gravity and 1° in phase lag. The similar result was also reported by L. Steinmetz (**22**) and P. Melchior (**23**). In the present article, the hourly values alone were used for analysis. The hourly values of gravity change at eleven stations thus obtained are collectively shown in the table at the end of the present article.

Table 1.7. Average values of drift speed determined by Pertzev's method

Station number	Drift speed (μgal/day)
1	+ 33.1
2	+ 3.6
3	+ 8.4
4	− 16.1
5	+ 12.4
6	+ 7.1
7	+ 25.9
8	+ 19.3
9	+ 20.6
10	− 15.6
11	+ 18.4

(2) Elimination of drift curve

As the drift is inevitably included in observational data of the tidal variation of gravity, the drift of gravime-

Table 1.8. Values

Harmonic analysis :

Station number	M_2 R (μgal)	M_2 ε (degree)	S_2 R (μgal)	S_2 ε (degree)	N_2 R (μgal)	N_2 ε (degree)
1	59.464±0.100	211.33±0.10	21.993±0.098	256.22±0.27	12.897±0.102	28.52±0.47
2	56.071±0.124	242.18±0.14	29.536±0.123	280.18±0.25	11.636±0.127	37.33±0.65
3	64.778±0.179	248.92±0.17	32.957±0.177	288.93±0.32	14.190±0.184	193.68±0.75
4	61.393±0.131	277.50±0.14	28.892±0.129	253.78±0.27	13.074±0.134	302.42±0.62
5	71.907±0.197	307.68±0.17	34.202±0.195	259.88±0.34	15.210±0.202	135.05±0.77
6	57.825±0.172	6.58±0.19	21.680±0.170	264.50±0.50	9.749±0.177	332.48±1.07
7	49.360±0.115	223.00±0.14	22.387±0.114	286.35±0.30	7.772±0.118	220.52±0.89
8	51.523±0.146	199.27±0.17	26.958±0.144	286.63±0.32	12.566±0.150	327.97±0.70
9	60.767±0.167	177.93±0.17	30.009±0.165	290.12±0.34	13.013±0.171	102.10±0.82
10	60.155±0.140	241.00±0.14	29.773±0.138	267.00±0.30	8.622±0.144	318.50±0.99
11	62.224±0.133	332.15±0.14	29.394±0.131	266.23±0.29	11.528±0.136	187.93±0.69

Harmonic analysis :

Station number	M_2 R (μgal)	M_2 ε (degree)	S_2 R (μgal)	S_2 ε (degree)	N_2 R (μgal)	N_2 ε (degree)
1	57.630±0.100	178.45±0.10	25.324±0.097	176.67±0.27	12.256±0.101	174.03±0.49
2	54.640±0.124	178.67±0.15	24.905±0.121	181.60±0.29	9.704±0.126	169.07±0.77
3	62.926±0.179	177.78±0.19	29.653±0.175	179.33±0.36	12.260±0.182	173.84±0.87
4	59.123±0.131	179.58±0.14	26.570±0.128	175.39±0.52	11.551±0.133	173.58±0.69
5	69.422±0.197	177.06±0.17	31.551±0.192	175.38±0.37	13.344±0.200	177.59±0.89
6	56.061±0.172	178.92±0.19	27.543±0.168	178.98±0.37	11.212±0.175	173.13±0.92
7	47.479±0.115	180.45±0.15	21.138±0.112	183.80±0.32	8.534±0.117	175.21±0.82
8	50.333±0.146	180.72±0.19	22.563±0.142	177.56±0.37	10.173±0.148	158.54±0.84
9	58.781±0.167	178.32±0.17	32.031±0.163	180.03±0.31	10.809±0.169	172.41±0.94
10	57.045±0.140	174.62±0.15	25.650±0.136	185.48±0.32	9.734±0.142	179.24±0.86
11	60.191±0.133	177.08±0.14	29.224±0.129	175.69±0.27	10.241±0.134	175.82±0.76

of R_{obs} and ε_{obs}

Lecolazet's method

K_1		O_1		Q_1	
R (μgal)	ε (degree)	R (μgal)	ε (degree)	R (μgal)	ε (degree)
49.193±0.109	63.50±0.14	29.520±0.106	312.88±0.22	5.547±0.106	140.05±1.14
23.578±0.135	144.93±0.34	24.582±0.132	286.25±0.34	6.343±0.132	68.97±1.29
57.135±0.195	182.97±0.20	31.189±0.191	253.38±0.37	8.796±0.191	193.58±1.27
43.290±0.143	245.04±0.19	24.476±0.139	181.63±0.34	4.219±0.139	220.47±1.97
28.933±0.215	23.63±0.45	26.295±0.210	141.67±0.47	3.819±0.210	10.63±3.20
49.888±0.188	50.67±0.22	24.964±0.183	130.03±0.44	4.614±0.183	105.00±2.72
45.502±0.125	94.60±0.17	33.896±0.123	280.50±0.22	5.941±0.123	294.62±1.25
29.331±0.159	169.18±0.32	28.294±0.155	215.60±0.34	5.637±0.155	342.62±1.62
65.840±0.182	195.82±0.17	27.580±0.178	148.73±0.39	3.986±0.178	171.63±2.57
49.320±0.152	244.17±0.19	26.286±0.149	129.60±0.34	12.859±0.149	178.97±0.67
40.501±0.145	19.48±0.22	23.977±0.141	155.22±0.35	8.555±0.141	29.97±0.97

Doodson-Lennon's method

K_1		O_1		Q_1	
R (μgal)	ε (degree)	R (μgal)	ε (degree)	R (μgal)	ε (degree)
45.092±0.157	181.75±0.21	34.249±0.143	182.04±0.26	7.497±0.143	182.48±1.11
36.627±0.196	201.35±0.32	29.617±0.178	183.76±0.36	6.440±0.178	168.13±1.66
64.855±0.283	164.26±0.26	39.971±0.257	185.21±0.39	10.236±0.257	154.04±1.49
45.175±0.206	173.48±0.27	33.466±0.188	178.90±0.34	4.734±0.188	203.59±2.46
33.958±0.311	203.43±0.56	34.155±0.283	176.06±0.49	5.266±0.283	217.30±3.89
43.954±0.272	179.71±0.37	28.963±0.247	177.44±0.51	6.491±0.247	196.21±2.21
53.346±0.181	180.49±0.22	41.367±0.165	180.48±0.24	7.399±0.165	154.08±1.32
46.551±0.230	185.44±0.29	33.161±0.210	180.50±0.41	4.401±0.210	160.44±2.87
62.119±0.263	159.70±0.26	35.061±0.240	184.27±0.41	5.104±0.240	198.03±2.74
65.745±0.220	157.79±0.21	37.050±0.201	173.19±0.32	11.931±0.201	177.85±1.01
42.441±0.209	183.07±0.31	30.051±0.190	171.76±0.37	8.784±0.190	184.62±1.46

Table 1.9. Values

Harmonic analysis :

Station number	M_2		S_2		N_2	
	R (μgal)	ε (degree)	R (μgal)	ε (degree)	R (μgal)	ε (degree)
1	52.011	212.45	20.070	260.13	10.388	33.02
2	49.695	243.07	26.774	278.21	11.284	38.42
3	52.289	251.07	26.181	290.66	10.536	197.24
4	53.812	277.73	26.778	258.77	10.895	312.33
5	60.085	310.92	29.742	264.45	12.993	138.22
6	51.871	7.82	18.007	265.82	8.100	333.49
7	41.443	222.64	19.771	284.12	7.337	227.00
8	46.399	197.54	25.059	290.21	9.878	342.50
9	51.511	177.38	22.860	293.28	10.831	105.78
10	51.800	247.44	27.237	258.55	8.344	293.08
11	55.150	334.85	24.538	269.81	11.743	192.28

Harmonic analysis :

Station number	M_2		S_2		N_2	
	R (μgal)	ε (degree)	R (μgal)	ε (degree)	R (μgal)	ε (degree)
1	50.307	180.00	23.465	180.00	9.632	180.00
2	48.460	180.00	22.603	180.00	9.278	180.00
3	50.834	180.00	23.711	180.00	9.733	180.00
4	52.218	180.00	24.356	180.00	9.998	180.00
5	57.997	180.00	27.051	180.00	11.105	180.00
6	50.307	180.00	23.465	180.00	9.632	180.00
7	39.773	180.00	18.551	180.00	7.615	180.00
8	45.188	180.00	21.077	180.00	8.652	180.00
9	50.042	180.00	23.342	180.00	9.581	180.00
10	49.715	180.00	23.189	180.00	9.519	180.00
11	52.891	180.00	24.670	180.00	10.127	180.00

of R_{theor} and ε_{theor}

Lecolazet's method

K_1		O_1		Q_1	
R (μgal)	ε (degree)	R (μgal)	ε (degree)	R (μgal)	ε (degree)
46.206	62.82	25.381	312.67	4.987	132.47
26.207	125.53	24.453	283.63	5.500	78.87
35.703	199.96	24.189	247.03	4.924	206.74
38.630	253.70	22.794	181.17	5.303	211.64
28.740	0.74	20.667	149.08	4.430	15.32
48.100	52.08	24.687	131.31	4.056	91.83
35.989	94.30	25.242	282.81	4.979	297.28
25.952	166.92	24.689	216.48	5.876	357.48
43.973	216.40	24.536	153.86	4.537	171.19
30.043	268.87	22.476	135.55	4.568	179.02
37.147	16.19	22.526	159.14	5.264	23.26

Doodson-Lennon's method

K_1		O_1		Q_1	
R (μgal)	ε (degree)	R (μgal)	ε (degree)	R (μgal)	ε (degree)
40.930	180.00	29.078	180.00	5.567	180.00
41.664	180.00	29.600	180.00	5.667	180.00
40.696	180.00	28.912	180.00	5.536	180.00
40.033	180.00	28.441	180.00	5.446	180.00
36.366	180.00	25.836	180.00	4.947	180.00
40.930	180.00	29.078	180.00	5.567	180.00
43.547	180.00	30.938	180.00	5.924	180.00
42.668	180.00	30.313	180.00	5.804	180.00
41.043	180.00	29.158	180.00	5.583	180.00
41.179	180.00	29.255	180.00	5.601	180.00
39.683	180.00	28.192	180.00	5.398	180.00

ter must be eliminated, first of all, from the data to obtain an accurate value of tidal factor. About this a detailed study will be made in the next article (**24**) of the present study. In conclusion, it may be stated that Pertzev's method is the excellent one for the present purpose. At the Third International Symposium on Earth Tides held at Trieste in July 1959, they resolved so as 'to eliminate the drift of gravimeter by applying Pertzev's method prior to beginning a harmonic analysis' (**25**).

Therefore, the drift curve was eliminated from all the hourly observed values by the method proposed by B. P. Pertzev (**26**). Calculations were carried out by the electronic computing machine 'IBM-650' at the Centre International des Marées Terrestres in Bruxelles, and average value of the drift speed determined by Pertzev's method for each period of observation, was shown in Table 1.7 (**27**).

At that time when the Askania gravimeter No. 111 was imported, its drift was about 40 μgal/day. Later, it began to show a tendency to decrease gradually and showed the last about 10 μgal/day.

(3) Harmonic analysis

After reduction of the drift, the hourly values were harmoniously analysed. As for the method of harmonic analysis, there are many methods devised by G. H. Darwin (**28**), A. T. Doodson (**29**), R. Lecolazet (**30**), G. W. Lennon (**31**), B. P. Pertzev (**32**) and others, but there is no conclusion generally accepted up to now which is the most excellent. Since it was also one of the present purposes to investigate it in detail, the harmonic analysis of the data was carried out by two different methods……namely the method of Lecolazet and that of Doodson-Lennon (second approximation)……calculations also carried out by the 'IBM-650' at Bruxelles as well as the calculations of drift-elimination.

By harmonic analysis, ten major tidal constituents were obtained by Lecolazet's method, while twelve by Doodson-Lennon's. In the present article, only the results for six principal tidal constituents……M_2 (principal lunar semi-diurnal constituent), S_2 (principal solar semi-diurnal constituent), N_2 (larger lunar elliptic semi-diurnal constituent), K_1 (luni-solar declinational diurnal constituent), O_1 (lunar declinational diurnal constituent) and Q_1 (lunar elliptic diurnal constituent)……were described. The other constituents were not discussed, because their amplitudes were too small to

Table 1.10. Values of G and κ

Harmonic analysis : Lecolazet's method

Station number	Central epoch (UT)	M_2		S_2		N_2		K_1		O_1		Q_1	
		G	κ	G	κ	G	κ	G	κ	G	κ	G	κ
1	July 14, 18h, 1957	1.143±0.003	−1°.12±0°.11	1.096±0.006	−3°.91±0°.28	1.242±0.011	− 4°.50±0°.48	1.065±0.003	+ 0°.68±0°.14	1.163±0.005	+0°.21±0°.23	1.112±0.022	+ 7°.58±1°.14
2	Sept. 10, 18h, 1957	1.128±0.003	−0.89±0.14	1.103±0.005	+1.97±0.26	1.031±0.012	− 1.09±0.66	0.900±0.006	+19.40±0.34	1.005±0.006	+2.62±0.34	1.153±0.025	− 9.90±1.29
3	Oct. 24, 18h, 1957	1.239±0.004	−2.15±0.18	1.259±0.007	−1.73±0.33	1.347±0.018	− 3.56±0.76	1.600±0.006	−16.99±0.21	1.289±0.009	+6.35±0.38	1.786±0.040	−13.16±1.28
4	Feb. 3, 18h, 1958	1.141±0.003	−0.23±0.14	1.079±0.005	−4.99±0.28	1.200±0.013	− 9.91±0.63	1.121±0.005	− 8.66±0.19	1.074±0.007	+0.46±0.34	0.796±0.027	+ 8.83±1.98
5	Apr. 16, 18h, 1958	1.197±0.004	−3.24±0.18	1.150±0.007	−4.57±0.34	1.171±0.016	− 3.17±0.78	1.007±0.008	+22.89±0.46	1.272±0.011	−7.41±0.48	0.862±0.048	− 4.67±3.21
6	June 27, 18h, 1958	1.115±0.004	−1.24±0.19	1.204±0.010	−1.32±0.51	1.204±0.023	− 1.01±1.08	1.037±0.005	− 1.41±0.23	1.011±0.008	−1.28±0.44	1.138±0.046	+13.17±2.73
7	Aug. 17, 18h, 1958	1.191±0.003	+0.36±0.14	1.132±0.007	+2.23±0.31	1.059±0.017	− 6.48±0.89	1.264±0.004	+ 0.30±0.18	1.343±0.005	−2.31±0.23	1.193±0.025	− 2.66±1.26
8	Oct. 1, 18h, 1958	1.110±0.004	+1.73±0.18	1.076±0.006	−3.58±0.33	1.272±0.016	−14.53±0.71	1.130±0.007	+ 2.26±0.33	1.146±0.007	−0.88±0.34	0.959±0.027	−14.86±1.63
9	Nov. 15, 18h, 1958	1.180±0.004	+0.55±0.18	1.313±0.008	−3.16±0.34	1.201±0.017	− 3.68±0.83	1.497±0.005	−20.58±0.18	1.124±0.008	−5.13±0.39	0.879±0.040	+ 0.44±2.58
10	Feb. 23, 18h, 1959	1.161±0.003	−6.44±0.14	1.093±0.006	+8.45±0.31	1.033±0.018	+25.42±0.99	1.642±0.006	−24.70±0.19	1.170±0.008	−5.95±0.34	2.815±0.033	− 0.05±0.68
11	May 4, 18h, 1959	1.128±0.003	−2.70±0.14	1.198±0.006	−3.58±0.29	0.982±0.012	− 4.35±0.69	1.090±0.005	+ 3.29±0.23	1.064±0.007	−3.92±0.36	1.625±0.027	+ 6.71±0.98

Harmonic analysis : Doodson-Lennon's method

Station number	Central epoch (UT)	M_2		S_2		N_2		K_1		O_1		Q_1	
		G	κ	G	κ	G	κ	G	κ	G	κ	G	κ
1	July 14, 00h, 1957	1.146±0.003	−1°.55±0°.11	1.079±0.005	−3°.33±0°.28	1.272±0.011	− 5°.97±0°.49	1.102±0.005	+ 1°.75±0°.21	1.178±0.006	+2°.04±0°.26	1.347±0.026	+ 2°.48±1°.11
2	Sept. 10, 00h, 1957	1.128±0.004	−1.33±0.16	1.102±0.006	+1.60±0.29	1.046±0.014	−10.93±0.78	0.879±0.005	+21.35±0.33	1.001±0.007	+3.76±0.36	1.136±0.032	−11.87±1.66
3	Oct. 24, 00h, 1957	1.238±0.004	−2.22±0.19	1.251±0.008	−0.67±0.36	1.260±0.019	− 6.16±0.88	1.594±0.008	−15.74±0.26	1.383±0.010	+5.21±0.39	1.849±0.047	−25.96±1.49
4	Feb. 3, 00h, 1958	1.132±0.003	−0.42±0.14	1.091±0.006	−4.61±0.53	1.155±0.014	− 6.42±0.69	1.128±0.006	− 6.52±0.28	1.177±0.007	−1.10±0.34	0.869±0.035	+23.59±2.46
5	Apr. 16, 00h, 1958	1.197±0.004	−2.94±0.18	1.166±0.008	−4.62±0.38	1.202±0.019	− 2.41±0.89	0.934±0.009	+23.43±0.56	1.322±0.011	−3.94±0.49	1.064±0.058	+37.30±3.89
6	June 27, 00h, 1958	1.114±0.004	−1.08±0.19	1.174±0.008	−1.02±0.38	1.164±0.019	− 6.87±0.93	1.074±0.007	− 0.29±0.38	0.996±0.009	−2.56±0.51	1.166±0.045	+16.21±2.21
7	Aug. 17, 00h, 1958	1.194±0.004	+0.45±0.16	1.139±0.007	+3.80±0.33	1.121±0.016	− 4.79±0.83	1.225±0.005	+ 0.49±0.23	1.337±0.006	+0.48±0.24	1.249±0.028	−25.92±1.33
8	Oct. 1, 00h, 1958	1.114±0.004	+0.72±0.19	1.071±0.008	−2.44±0.38	1.176±0.018	−21.46±0.84	1.091±0.006	+ 5.44±0.29	1.094±0.007	+0.50±0.41	0.758±0.037	−19.56±2.88
9	Nov. 15, 00h, 1958	1.175±0.004	−1.68±0.18	1.372±0.008	+0.03±0.31	1.128±0.018	− 7.59±0.94	1.514±0.007	−20.30±0.26	1.202±0.009	+4.27±0.41	0.914±0.044	+18.03±2.74
10	Feb. 23, 00h, 1959	1.147±0.004	−5.38±0.16	1.106±0.006	+5.48±0.33	1.023±0.016	− 0.76±0.86	1.597±0.006	−22.21±0.21	1.266±0.008	−6.81±0.33	2.130±0.036	− 2.15±1.01
11	May 4, 00h, 1959	1.138±0.003	−2.92±0.14	1.185±0.006	−4.31±0.28	1.011±0.014	− 4.18±0.76	1.070±0.006	+ 3.07±0.31	1.066±0.007	−8.24±0.38	1.627±0.036	+ 4.62±1.46

be expected of deducing any significant results from the observational data of one month.

In Table 1.8 are shown, the actual amplitude R_{obs} and phase ε_{obs} of each gravity constituent obtained by harmonic analysis. The results of harmonic analysis can be expressed in the form $R_{obs}\cos(nt+\varepsilon_{obs})$ for each constituent. The mean errors of R_{obs} and ε_{obs} shown in this table are results of computation using error combination introduced by R. Lecolazet (**33**).

On the other hand, the theoretical values of the tidal variation of gravity can theoretically be calculated for respective method. The theoretical values of R_{theor} and ε_{theor} corresponding to R_{obs} and ε_{obs} are shown in Table 1.9.

Thus, the tidal factor of gravity G and phase lag κ are calculated by the formulae

$$G=\frac{R_{obs}}{R_{theor}} \qquad \text{and} \qquad \kappa=\varepsilon_{obs}-\varepsilon_{theor} \tag{1.9}$$

respectively. The obtained values of G and κ are shown in Table 1.10 with the epoch of analysis. Here, the positive sign of κ shows that the observed tide advances the theoretical one, while the negative sign shows the former lags behind the latter.

(4) Corresponding harmonic terms of temperature and pressure

Although the gravimeter was in a double thermostat and pressure tight, the effect by changes of room temperature and atmospheric pressure upon the gravimeter was observed in a certain degree. It was necessary to assess the possible influence of temperature and pressure variations upon the harmonic constituents of gravity. In order to investigate it, the hourly observed values of room temperature and atmospheric pressure during the corresponding periods were analysed harmoniously by Lecolazet's method as well as the gravimetric data. Table 1.11 showed results corresponding to Table 1.8.

5. Discussion

Results of harmonic analysis were obtained for six major tidal constituents at eleven stations. As could easily be seen from Table 1.10, the

Table 1.11. Values of pseudoharmonic terms of
Room temperature

Station number	M_2		S_2		N_2	
	R (0.01°C)	ε (degree)	R (0.01°C)	ε (degree)	R (0.01°C)	ε (degree)
1	0.339	300.12	0.696	138.97	0.571	80.22
2	2.221	99.48	13.663	88.30	1.745	11.10
3	0.566	30.97	7.772	336.73	2.027	201.72
4	1.926	358.07	5.665	90.45	2.512	114.03
5	1.407	270.12	4.309	237.77	2.480	269.00
6	5.961	29.70	3.205	197.80	6.476	348.42
7	1.837	197.10	0.292	187.08	0.882	170.42
8	0.176	187.85	0.844	113.77	1.208	11.55
9	4.226	304.03	10.670	335.42	7.917	16.55
10	9.609	121.60	10.520	6.57	11.457	53.13
11	0.638	36.13	0.851	144.42	0.514	68.67

Atmospheric pressure

Station number	M_2		S_2		N_2	
	R (0.01mmHg)	ε (degree)	R (0.01mmHg)	ε (degree)	R (0.01mmHg)	ε (degree)
1	1.616	339.03	16.922	138.18	3.161	276.47
2	8.124	194.22	40.807	166.77	3.904	201.08
3	3.551	65.58	32.627	154.52	1.874	348.12
4	12.303	48.48	50.501	186.50	4.590	116.47
5	13.679	145.50	39.953	147.02	7.448	218.00
6	2.410	194.87	34.413	162.07	7.974	301.87
7	2.590	273.15	31.470	183.35	2.525	68.68
8	3.205	194.52	26.469	184.48	7.762	101.37
9	6.323	65.45	36.451	155.50	6.879	76.67
10	25.666	85.70	56.015	156.02	22.665	254.90
11	1.674	247.52	28.905	110.97	2.051	79.22

room temperature and atmospheric pressure

K_1		O_1		Q_1	
R (0.01°C)	ε (degree)	R (0.01°C)	ε (degree)	R (0.01°C)	ε (degree)
6.693	122.50	2.413	94.20	1.041	104.97
37.071	179.40	5.318	10.10	4.312	264.60
38.078	97.57	2.993	331.48	3.627	299.15
13.361	123.77	4.289	43.95	4.063	96.08
20.968	66.43	5.235	57.93	0.961	13.78
5.077	177.12	12.567	286.72	5.394	153.52
1.243	25.55	3.213	339.93	2.797	311.70
4.619	94.58	2.922	192.17	1.546	222.77
53.060	108.90	6.431	28.50	17.974	156.87
72.762	143.57	19.128	5.52	11.059	70.05
2.821	7.53	0.464	7.32	1.339	279.12

K_1		O_1		Q_1	
R (0.01mmHg)	ε (degree)	R (0.01mmHg)	ε (degree)	R (0.01mmHg)	ε (degree)
17.662	312.02	8.102	232.52	5.191	32.80
40.047	319.90	20.151	130.03	15.679	137.78
29.110	312.02	12.054	180.88	16.802	45.23
42.852	290.87	22.257	320.28	31.207	320.13
17.398	308.88	5.163	158.53	5.481	176.22
44.695	344.52	8.528	141.77	10.741	46.13
2.570	188.00	14.679	94.88	3.506	311.25
34.218	329.80	33.099	49.50	20.392	283.13
29.508	301.28	7.679	220.68	9.271	261.38
20.023	209.40	44.783	59.87	40.195	209.42
14.590	308.48	6.740	203.97	8.129	352.80

values of G and κ for M_2-constituent obtained at each station, were in good accordance with each other, while those for other constituents were largely diverse from each other in the results by both Lecolazet's and Doodson-Lennon's methods. Even in the results obtained at one station, the values of G and κ for each constituent were considerably diverse. The observation period of one month was certainly too short to obtain an accurate value of every tidal wave except M_2-constituent. The amplitude of M_2-constituent is really in 90% of total lunar tides and, as shown in Fig. 1.4, its amplitude is of the largest at a region of low latitudes near equator. From these reasons, only the value of M_2-constituent was considered to be highly trustworthy for the discussion of the tidal factor of gravity, consequently the succeeding discussions restricted to the M_2-constituent

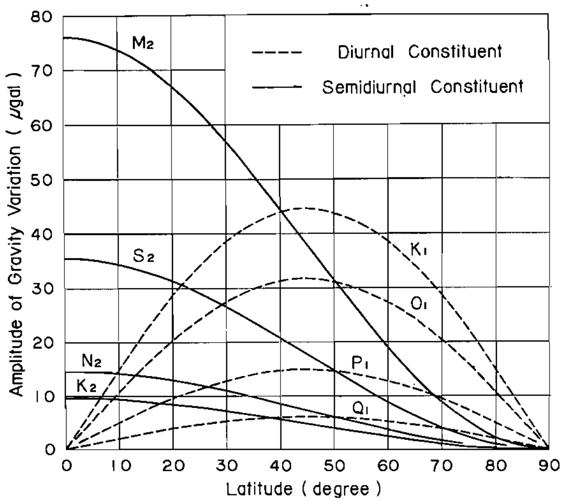


Fig. 1.4. Change of amplitude of tidal constituents with latitude.

Table 1.12. Corrected tidal factor for M_2-constituent

Station number	Lecolazet's method	Doodson-Lennon's method
1	1.142	1.145
2	1.127	1.127
3	1.238	1.237
4	1.140	1.131
5	1.196	1.196
6	1.114	1.113
7	1.190	1.193
8	1.109	1.113
9	1.179	1.174
10	1.160	1.146
11	1.127	1.137

alone.

(1) Elimination of drift curve

As the values in Table 1.10 were the results obtained from the harmonic analysis by Lecolazet's or Doodson-Lennon's method after elimination of the drift by Pertzev's method, they could not be treated as real values. Then, by applying the correction factor (**34**) introduced by the author, the real tidal factor of gravity which was perfectly free from the drift-elimination, was calculated, and the results tabulated as in Table 1.12.

(2) Method of harmonic analysis

Difference in analytical results due to applying different methods of harmonic analysis has been investigated by many researchers. For example, P. Melchior (**35**) investigated the problem in detail by using the observational tides and B. P. Pertzev and others (**36**) by the theoretical ones. The author has also investigated this problem for several years.

As shown in Table 1.10, concerning the tidal factor of gravity for M_2-constituent, the difference in results between Lecolazet's and Doodson-Lennon's methods is only 1.2% in maximum. As for the phase lag, it is 2° maximum, generally within 1°. But a methodical difference of this degree can no longer be a subject of discussion and therefore it is to be stated that the difference in results due to applying different methods of harmonic analysis, may not be worth a notice.

Methodical superiority of harmonic analysis be synthetically judged taking into consideration the ability of drift-elimination, the degree of exclusion of the influence of other constituents upon the one concerned, the accuracy of result being limited by the method of analysis, the labour of calculation, etc. The investigation on this problem will be made in the next article (**24**) of the present study. It is ascertained in the succeeding article that Lecolazet's method has given comparatively good results in the present treatment.

(3) Time of observation

The problem whether the value of the tidal factor of gravity changes with time at any one point or worldwidely is very speculative and attractive. The distance between the observation room of Kyoto (I) and that of Kyoto (II) was about 300 metres and their observation epoch differed about one year, and the observational results of both stations showed no changes in phase lag, but the difference was about 3% in tidal factor of the M_2-constituent. In comparison with the result of one month's observation by a Worden gravimeter in June–July 1954 (see Table 1.15) at the same place in Kyoto (I), the difference in tidal factor for M_2-constituent was also about 3% even if there were differences in the instrument, the time of observation and the method of analysis. Quite a similar tendency was recognized also in the results obtained at Shionomisaki.

In order to investigate whether these facts can be approved as time change of the tidal factor of gravity, or not, and also what degree of confidence may be derived from the results obtained by one month's observation, a long period observation be continued up to the present time at Kyoto (II) by means of the Askania gravimeter No. 111. Details on such investigations will be described in an another article (**37**) of the present study.

(4) Altitudinal difference of the observation stations

The tide-generating potential at any point on the earth is proportional to the square of distance from the centre of the earth. Vertical component of tidal force is, therefore, proportional to the distance from the earth's centre. In the present case, the maximum height difference between eleven stations was about 560 metres and the effect due to this height difference was estimated to be about 10^{-4} of the original force. Therefore, so far as a number of four figures is adopted in discussing the tidal factor of gravity, the effect on the value of the tidal factor of gravity by the height difference between the observation stations, may safely be disregarded.

(5) Influence of oceanic tides

What is regarded to have the most important effect upon the tidal factor of gravity are, as already described in section 1, the oceanic tides. In particular, as Japan is surrounded by oceans, the oceanic tides must exert some influences even on the inland station. Their effect is generally consisted of three principal parts. The first is the effect of the vertical component of the gravitational attraction by the tidal change of sea water ; the second, the effect of elastic deformation of the solid earth due to the tidal load of sea water ; and the third, the effect caused by distorsion of the potential field due to deformation by tidal load.

Investigations of these oceanic influences have been made theoretically (**3**), numerically (**38, 39**) and empirically (**40, 41, 42, 43, 44**) by many investigators. In the following, a trial to numerically correct the observed values is described.

The first influence can be calculated by use of a cotidal chart of the oceanic waters (**45**). Let r and φ be radius vector and azimuth on the earth's surface and z vertical inward, taking the observation station as an origin of the coordinate. The attraction g_z of the sea water with volume $rdrd\varphi dz$ situated on (r, φ, z) is expressed by

$$g_z=\gamma\rho\frac{rzdrd\varphi dz}{(r^2+z^2)^{3/2}}, \tag{1.10}$$

where γ is the gravitational constant and ρ the density of oceanic water. Assuming that the surface of the earth is a plane and that a sea surface is in constant height, the attraction of sea water within a zone bounded by radii r_1 and r_2, azimuths φ_1 and φ_2 and heights z_1 and z_2 is calculated as follows :

$$\begin{aligned} g_z&=\gamma\rho\int_{\varphi_1}^{\varphi_2}d\varphi\int_{r_1}^{r_2}rdr\int_{z_1}^{z_2}\frac{z}{(r^2+z^2)^{3/2}}dz \\ &=\frac{\gamma\rho(r_2-r_1)(\varphi_2-\varphi_1)(z_2^2-z_1^2)}{2r_1r_2} \end{aligned} \tag{1.11}$$

Let R, ω and η be the amplitude, velocity and phase lag of a constituent of the varing sea water, respectively, and d be the height of the observation station. Since an oscillation of the oceanic water is expressed by the form of $R\cos(\omega t+\eta)$ for each constituent, the equation (1.11) becomes

$$g_z\doteqdot\frac{\gamma\rho(r_2-r_1)(\varphi_2-\varphi_1)(2d+R\cos\eta)R\cos(\omega t+\eta)}{2r_1r_2}. \tag{1.12}$$

Here the formula (1.12) gives g in gals when r, d and R are in centimetres.

In practical calculation, it is a problem what area of a sea one should take into account. A considerably wide area must be taken into account in case of a tiltmetric observation, but, in a gravimetric observation, the gravimetric attraction due to the tidal water within a range of radius of 1° from the observation station, includes more than 99% of the total attractions when its station is situated at a coast and more than 90% in other cases. The vertical component of attraction with M_2-period arising from

Table 1.13. The vertical component of attraction by M_2-constituent of the oceanic tides

Station number	Vertical attraction (μgal)
1	$0.001 \cos(2t+167.6^\circ)$
2	$0.002 \cos(2t+279.0)$
3	$0.791 \cos(2t+197.0)$
4	$1.690 \cos(2t+185.4)$
5	$0.116 \cos(2t+160.3)$
6	$0.001 \cos(2t+167.6)$
7	$0.189 \cos(2t+254.5)$
8	$0.002 \cos(2t+244.6)$
9	$0.243 \cos(2t+210.4)$
10	$0.005 \cos(2t+299.2)$
11	$0.104 \cos(2t+110.7)$

the tidal variation of oceanic water within a range of radius of 1°, is shown in Table 1.13, the observation station being its centre.

As for the second influence, the Nagaoka's formula (**46**) on the elastic deformation of ground by surface load, is theoretically applicable. But in a practical case, the calculation is exceedingly troublesome. Regarding the third influence, no satisfactory theory so as to calculate its amount is known up to the present. Recently, the problem for deformation of an earth-model by surface pressure has been discussed by L. B. Slichter and M. Caputo (**47**).

Conveniently, in the present case, since there were many observation stations and they were selected by taking into consideration the distance from the seashore so as to investigate the influence of the oceanic tides upon the tidal variation of gravity, the experimental formula which was the most fitting the observational results, was examined. Practically the observed tides were separated into two terms, that is, one the primary component G_0 not disturbed by the oceanic tides and the other the second component which was effect of the oceanic tides.

In Fig. 1.5 is shown the relation between the vertical component of attraction by the tidal sea water and the tidal factor obtained by harmonic analysis after Lecolazet's method. The relation concerning the results by Doodson-Lennon's method, is shown in Fig. 1.6. A quite similar tendency is clearly recognized in these two figures.

In these figures, all plots are seen to be in a line except one for Shionomisaki (4). Assuming then the effect of oceanic tides upon the tidal variation of gravity is tentatively expressed by a function with vertical component of attraction of the oceanic tides as a parameter, that is, $a\times$ vertical attraction, and putting

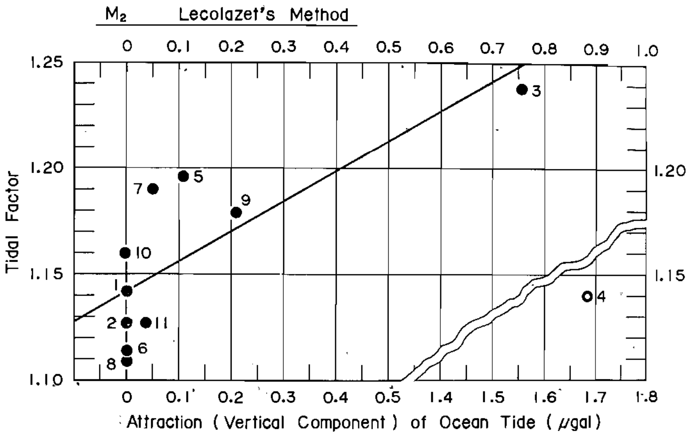


Fig. 1.5. Relation between the tidal factor obtained by Lecolazet's method and the vertical component of attraction by tidal water.

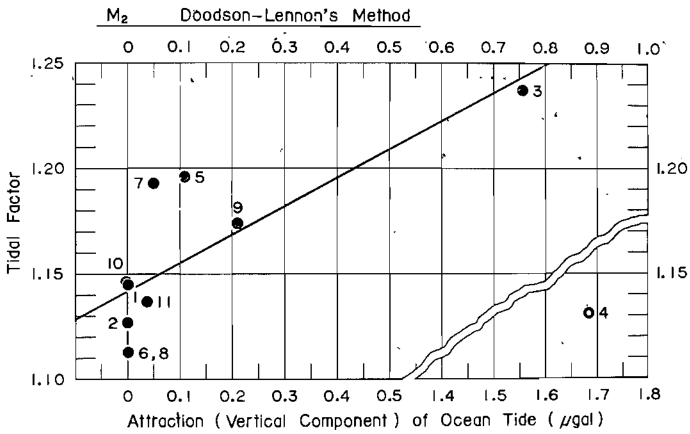


Fig. 1.6. Relation between the tidal factor obtained by Doodson-Lennon's method and the vertical component of attraction by tidal water.

$$\text{Observed tide} = G_0 \times \text{Theoretical tide} + a \times \text{Vertical attraction}, \qquad (1.13)$$

G_0 and a can be obtained by method of the least square using the observational results of ten stations except Shionomisaki. The values of G_0 and a thus obtained are shown in Table 1.14.

That is to say, G_0 is the tidal factor of gravity in Japan free from influence of the oceanic tides. There is no difference between the tidal factor of gravity obtained by Lecolazet's and Doodson-Lennon's methods.

Table 1.14. Values of G_0 and a

	Lecolazet's method	Doodson-Lennon's method
G_0	1.142 ± 0.011	1.142 ± 0.010
a	7.5 ± 2.2	6.9 ± 2.0

(6) Influence of the local geological and tectonic structure

In observation of the tidal deflection of plumb-line by a tiltmeter, the correlation between the phenomena on earth tides and the local geological structure around the observation station, has been in detail discussed by several investigators. For example, E. Nishimura (**39**) has studied the influence of the active fault at Beppu and R. Tomaschek (**48, 49**) the influence of the Alpine structure at several stations on the European Continent. On the contrary, a definitive conclusion has not yet obtained up to the present time concerning the problem of the local influence of the geological and tectonic structure upon the tidal variation of gravity. Mentioning a few examples for this problem, R. Tomaschek (**50**) explained that the difference in the tidal factor at two stations was attributed to the crustal movement of the mountain and K. Iida and others (**51**) that a large abnormal value of the tidal factor obtained at Ōshima-Motomura (see Table 1.15) was attributed to the special density distribution in this area.

Concerning the geological structure in Japan, the map of Bouguer anomalies compiled by C. Tsuboi (**7**) gives the most precise information. The relation between the deviation of each observed value from the experimental formula mentioned above and Bouguer anomaly is shown in Figs. 1.7 and 1.8 for the results by Lecolazet's and Doodson-Lennon's methods respectively.

Although the above obtained deviations shown in Figs. 1.7 and 1.8 are comparatively small, these are far beyond the limit of the error. In view of these figures, a certain relation seems to be existing between the obtained deviation and the value of Bouguer anomaly when the deviation at Mizusawa (8) is excluded. However the influence of the meteorological disturbances is included at this stage. After exclusion of the meteorological influences, this problem will be investigated again in detail (**37**).

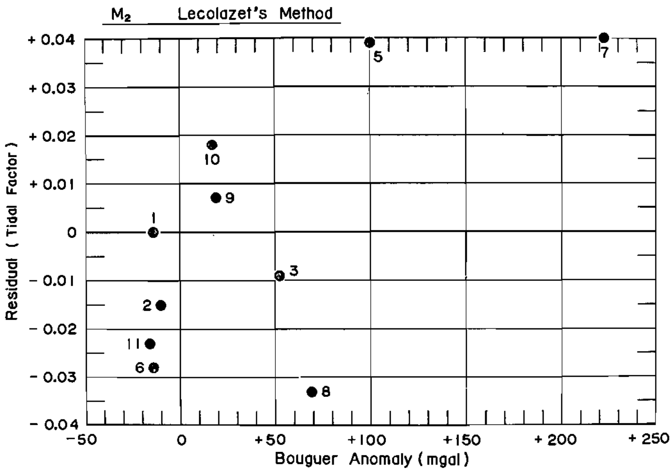


Fig. 1.7. Relation between the deviation of each observation from the experimental formula and Bouguer anomaly (for Lecolazet's method).

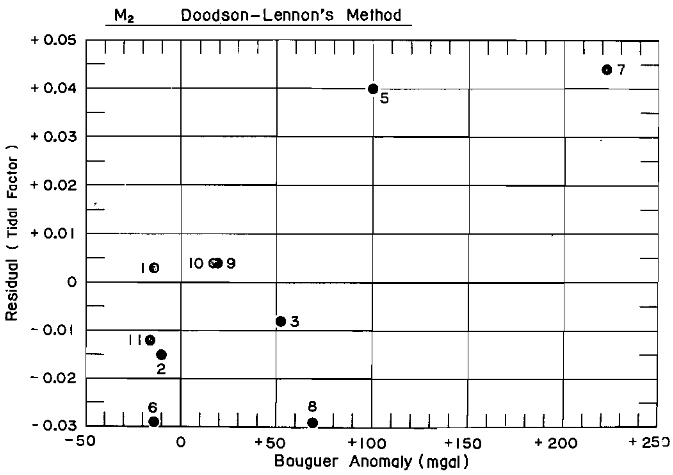


Fig. 1.8. Relation between the deviation of each observation from the experimental formula and Bouguer anomaly (for Doodson-Lennon's method).

(7) Meteorological influences

Although many investigators have pointed out that changes in temperature and atmospheric pressure affect mode of gravity variation to a certain degree, few reports are published with definite conclusions (**21**, **49**, **52**). In the tiltmetric observation, the amplitude of the meteorological influences may sometimes considerably exceed the direct tidal amplitude of the earth itself. So the meteorological correction for the observed tides is of great importance. The changes of the meteorological factors such as temperature and atmospheric pressure affect a gravimeter both directly and indirectly, and are represented as apparent change of gravity. Therefore the extent of influence is usually different due to the gravimeter in use in the observation. The correction coefficients of the Askania gravimeter No. 111 for the changes of temperature and pressure, are found from one year's observation of the tidal variation of gravity at Kyoto (II) and reported later (**37**) in detail. When corrections for the meteorological changes are taken into account in Figs. 1.7 and 1.8, a more obvious relationship between the geological structure and the tidal factor of gravity may be found.

(8) Instrument

It is necessary to check whether the same observational result can be obtained by more than two sets of gravimeters set side by side at the same place. In order to investigate it, a simultaneous observation was made at Kanozan by use of two Askania gravimeters of No. 105 and No. 111. The analytical results obtained at Kanozan by the Askania gravimeter No. 105 at the same epoch as the author made observation, reported that the tidal factor was 1.19 and the phase lag $+0.°92$ concerning the M_2-constituent (**53**). The results obtained by both gravimeters showed that there were differences by 1% in tidal factor and 1° in phase lag, although the treating method of their data differed.

But according to the results obtained by same kind of observations as at Kanozan in foreign countries, they obtained considerably different results both in tidal factor and in phase lag. In order to investigate this problem, simultaneous observations must necessarily be carried out with more than two gravimeters for a period longer than one year.

(9) Phase lag

In general, the phase lags found by observations showed very small value so far as the M_2-constituent was concerned. But these values did not show reality of the phase lag. As already indicated by a few researchers (**9**, **10**, **54**), there existed an instrumental lag (mainly due to a large inertia of the whole circuit of galvanometer for recording) in an Askania gravimeter. Although its value must be estimated by any method,

Table 1.15. Values of G and κ in Japan

Observation station	Latitude (N)	Longitude (E)	Instrument*	Year	Number of day	M_2 G	M_2 κ	Total G	Method of analysis	Author
Nikkō	36°44′	139°36′	N-108	1949, 50	2			1.34		
Motomura	34 45	139 21	N-108	1950, 51	8			1.63		K. Iida, M. Hayakawa & K. Katayose (51)
Kawasaki	35 35	139 37	N-108	1951	15	1.34				
Kyoto	35 02	135 47	W-127	1954	30	1.18	−1.96°		Darwin	
Chikubushima	35 25	136 09	W-127	1955	30	1.21	−1.20		Darwin	T. Ichinohe, I. Nakagawa & Y. Okamoto (56)
Shionomisaki	33 27	135 46	W-127	1955	30	1.23	−2.42		Darwin	
Chiba	35 38	140 06	A-105	1957 - 58	270	1.145	−0.04		Darwin	G. S. I. (53)
Kanozan	35 15	139 58	A-105	1958	150	1.204	+2.10		Darwin	

* N : North American W : Worden A : Askania

it had not been yet known. In the LaCoste-Romberg tidal gravimeter, it was reported that it amounted to about 15° for M_2-constituent (**55**).

One could point two points out in the matter of the phase lag on the M_2-constituent in Table 1.10. One the value at Tottori was far larger in comparison with other stations and the other the sign being opposite in Eastern Japan. As there existed many disturbances at Tottori, a resistance was inserted in the galvanometer's circuit in order to reduce the sensitivity of the gravimeter. As to the opposite sign, it showed that the observed tide advanced the theoretical in Eastern Japan, while in Central and Western Japan the observed tide lagged behind the theoretical.

(10) Comparison of the results

The observational results of the tidal variation of gravity hitherto obtained in Japan by several investigators (**51**, **53**, **56**) are shown in Table 1.15.

The stations at Kyoto and Shionomisaki shown in this table are the same places in Kyoto (I) and Shionomisaki throughout the present article. In the previous and present observations, there were only some differences in the instrument, the time of observation and the analysis method of the observational data. Nevertheless the values for all constituents in Table 1.10 were lower than those in Table 1.15. One would attribute that to a difference in measuring and in the scale constant of both gravimeters, rather than to the time change of the tidal factor of gravity itself.

The values at Chiba shown in Table 1.15 were obtained by use of the Askania gravimeter No. 105, the same type of gravimeter as the author used, during the International Geophysical Year. According to the author's calculation, the influence of the oceanic tides was negligibly small at Chiba. The values at Chiba were the results obtained, first of all, by eliminating the drift by moving mean of successive 25 hours and next by making a harmonic analysis applying Darwin's method. • Therefore, if one took no account of the difference in the analysis method of the data, one would conclude that the author's results were in good agreement with those at Chiba.

Furthermore, N. N. Pariisky and others (**57**, **58**) had observed the tidal variation of gravity by means of Askania gravimeters at Alma-Ata, Tachkent and Lantschou at distances of more than 1000 kilometres from the seashore free from influence of the oceanic tides. According to their results, the tidal factor of gravity for M_2-constituent was 1.14.

It is a noticeable fact that the most reliable value of the tidal factor of gravity in Japan free from the influence of the oceanic tides obtained by observations at eleven stations was in fairly good agreement with values obtained at some stations in Southeastern Asia, stations concerned being Chiba, Alma-Ata, Tachkent, Lantschou and others, but these values were much smaller than those in Europe at the same periods, as mentioned also by P. Melchior (**59**). The value of the tidal factor of gravity obtained by the author was also smaller than that derived in theoretical investigations by H. Takeuchi (**3**), H. Jeffreys (**60**), and C. L. Pekeris and others (**61**).

(11) Love's numbers

As repeatedly mentioned above, the value of the tidal factor of gravity in Japan free from the influence of the oceanic tides obtained from the present investigation was

$$G \equiv 1-\frac{3}{2}k+h=1.142\pm0.011\,. \tag{1.14}$$

On the other hand, the value of the diminishing factor obtained from the tiltmetric observation at Barin by E. Nishimura (**39**) was

$$D \equiv 1+k-h=0.661\pm0.024\,. \tag{1.15}$$

By combining both values, Love's numbers, h and k, are calculated as follows :

$$h=0.733 \qquad \text{and} \qquad k=0.394\,. \tag{1.16}$$

(12) Others

Observations at Naze were carried out during a period of about 40 days from March 29 to May 10, 1958. An annular eclipse occured on April 19, 1958, and Naze was situated in its zone. On the basis of the registrograms obtained at that time, the effect of gravitational screening was in detail investigated. It would be reported in a later article (**62**) of the present study.

6. Summary

In the present article, effects of local character of the observation station upon the tidal variation of gravity, were in detail discussed. Analysed data were obtained at eleven stations in Japan by means of the Askania Gs-11 gravimeter No. 111 during a period of about two years from July 1957 to May 1959 (International Geophysical Year). In order to investigate the effects of the oceanic tides and of the difference in the local geological and tectonic structure, the observation stations were particularly selected from two standpoints of both the distance from the effective sea and the gravity anomaly. The observation at one station was made continuously with automatic recording during 34 days, and the hourly values of 30 days were used for harmonic analysis. Drift curve of the gravimeter was eliminated by Pertzev's method and in order to discuss the methodical superiority, the harmonic analysis was made by each of Lecolazet's and Doodson-Lennon's methods. After various considerations for the results of harmonic analysis, the following conclusions were obtained.

(1) The most reliable value of the tidal factor of gravity in Japan free from the influence of the oceanic tides was 1.142 ± 0.011.

(2) The phase lag in the phenomena of earth tides was very small even if it existed.

The value of the tidal factor of gravity obtained from these considerations was in good agreement with that obtained at some stations in South-eastern Asia, but it was small in comparison with the tidal factor obtained in Europe or that of the theoretical investigations on earth tides.

In the present article, the results obtained by one month's observation at each station were discussed in some detail. But in order to make the further detailed discussion, it was necessary to investigate the degree of confidence of the results obtained by one month's observation. In the above-mentioned considerations, the influence caused by the change of meteorological factors was not excluded. In order to investigate to what extent the difference in the time of observation affected the obtained results and also to investigate the effect of the meteorological disturbances upon the tidal variation of gravity, a continuously precise observation for more than one year was found indispensable. Furthermore, it would be necessary to investigate whether the obtained results differed depending upon the difference of type of instrument used in observation. These problems being very important and would be discussed in an another article of the present study.

Among eleven stations, two at Shionomisaki and Mizusawa were treated as singular stations, the former from a standpoint of influence of the oceanic tides, and the latter the influence of the geological structure. On these causes a detailed investigation now in progress would be reported in due course of time.

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Hourly observed values of gravity

Instrument : Askania Gs-11 gravimeter No. 111

Observation period : July 1957 - May 1959 (374 days)

Gravity

June - July, 1957

Day \ Hour (UT)		0	1	2	3	4	5	6	7	8	9	10
June	28	1982	1770	1596	1495	1497	1616	1873	2094	2273	2387	2444
	29	1926	1655	1443	1289	1231	1302	1451	1635	1851	2110	2230
	30	2079	1890	1673	1499	1383	1387	1458	1608	1781	1991	2200
July	1	2223	2069	1847	1701	1581	1532	1537	1601	1753	1940	2173
	2	2254	2213	2101	1920	1778	1686	1669	1691	1787	1949	2163
	3	2317	2330	2304	2239	2145	2065	2004	1995	2041	2142	2284
	4	2466	2547	2595	2595	2563	2522	2464	2425	2417	2439	2486
	5	2414	2532	2649	2739	2785	2800	2787	2754	2728	2716	2735
	6	2441	2488	2604	2740	2851	2912	2941	2948	2929	2890	2869
	7	2378	2408	2515	2671	2791	2896	2966	3028	3029	2995	2948
	8	2452	2425	2497	2629	2756	2875	2990	3094	3200	3195	3119
	9	2523	2451	2462	2556	2691	2842	3018	3175	3286	3331	3302
	10	2692	2586	2560	2602	2708	2910	3103	3255	3356	3421	3426
	11	2925	2766	2682	2683	2787	2944	3134	3334	3485	3633	3652
	12	3205	3049	2924	2853	2891	3023	3165	3325	3527	3690	3762
	13	3440	3248	3114	3029	3024	3085	3234	3424	3593	3702	3773
	14	3547	3367	3204	3091	3041	3079	3200	3361	3551	3688	3767
	15	3639	3518	3364	3210	3117	3103	3193	3322	3480	3620	3720
	16	3720	3641	3529	3388	3288	3253	3272	3388	3521	3659	3780
	17	3812	3773	3707	3603	3533	3480	3481	3551	3647	3744	3828
	18	3895	3882	3855	3801	3736	3692	3692	3729	3778	3867	3971
	19	4033	4072	4070	4057	4036	4012	3990	3982	4022	4096	4203
	20	4150	4240	4305	4346	4366	4355	4328	4313	4305	4314	4347
	21	4018	4126	4232	4318	4384	4429	4439	4423	4408	4397	4413
	22	4080	4175	4314	4447	4545	4621	4673	4696	4683	4660	4639
	23	4235	4287	4399	4534	4664	4783	4888	4958	4983	4949	4900
	24	4405	4390	4490	4650	4839	5053	5215	5315	5346	5337	5292
	25	4725	4615	4630	4754	4940	5163	5350	5516	5665	5697	5665
	26	5076	4902	4825	4873	5022	5245	5533	5768	5905	5975	5976
	27	5421	5174	5001	4949	5039	5216	5438	5678	5858	5977	6020
	28	5617	5389	5124	5013	4988	5022	5192	5400	5633	5771	5862
	29	5704	5515	5316	5088	4982	4999	5132	5321	5528	5696	5793
	30	5648	5532	5354	5171	5015	4954	4993	5117	5309	5503	5634
	31	5564	5524	5410	5284	5144	5046	5024	5065	5205	5364	5507

Sensitivity : 2.6012 μgal/mm

Station : Kyoto (I)

11	12	13	14	15	16	17	18	19	20	21	22	23
2405	2317	2224	2110	2037	2025	2060	2150	2232	2296	2315	2264	2130
2271	2246	2139	1995	1864	1810	1849	1924	2050	2171	2256	2264	2196
2294	2308	2238	2138	2003	1890	1825	1843	1937	2083	2203	2273	2272
2302	2343	2332	2251	2122	1987	1863	1822	1851	1932	2049	2161	2234
2313	2402	2441	2392	2321	2239	2134	2042	1990	2015	2081	2163	2241
2457	2564	2623	2629	2587	2520	2410	2282	2208	2174	2184	2234	2335
2552	2635	2723	2778	2775	2721	2641	2516	2390	2320	2283	2288	2335
2773	2838	2939	3007	3049	3027	2951	2847	2697	2564	2488	2437	2427
2860	2871	2913	2956	3018	3045	3030	2951	2858	2736	2607	2495	2394
2920	2923	2943	2991	3047	3112	3148	3126	3052	2929	2801	2671	2552
3037	2980	2966	2979	3032	3122	3198	3218	3173	3063	2918	2779	2640
3214	3139	3057	3046	3103	3176	3262	3337	3343	3293	3181	3015	2823
3365	3291	3224	3188	3203	3261	3355	3457	3521	3511	3424	3271	3102
3599	3488	3375	3321	3300	3344	3420	3530	3663	3691	3665	3548	3354
3760	3692	3580	3457	3399	3408	3491	3631	3732	3824	3834	3784	3646
3774	3733	3653	3547	3474	3445	3454	3524	3624	3705	3764	3748	3667
3801	3779	3705	3613	3537	3481	3461	3501	3587	3681	3741	3760	3731
3774	3790	3754	3668	3570	3504	3474	3491	3543	3626	3705	3746	3754
3829	3844	3842	3792	3695	3591	3534	3531	3584	3648	3729	3792	3815
3902	3954	3954	3899	3824	3760	3696	3661	3668	3708	3766	3831	3878
4065	4151	4181	4173	4108	4009	3920	3852	3818	3820	3852	3896	3958
4307	4367	4407	4416	4396	4309	4216	4105	4002	3939	3929	3960	4045
4410	4466	4520	4532	4523	4482	4414	4301	4188	4073	3977	3943	3954
4442	4494	4555	4618	4652	4643	4597	4512	4405	4292	4182	4060	4038
4653	4673	4708	4753	4807	4857	4858	4814	4727	4625	4505	4362	4259
4854	4834	4846	4884	4964	5055	5131	5134	5088	4944	4774	4621	4481
5232	5172	5156	5186	5246	5310	5392	5457	5463	5398	5265	5118	4933
5564	5436	5375	5358	5388	5478	5635	5755	5812	5801	5706	5495	5275
5928	5817	5691	5603	5594	5657	5767	5899	5999	6025	6001	5884	5695
5961	5847	5707	5590	5540	5540	5608	5714	5822	5926	5977	5916	5780
5858	5783	5661	5526	5425	5381	5397	5476	5605	5725	5825	5861	5814
5841	5779	5665	5524	5372	5257	5210	5264	5393	5555	5653	5703	5715
5715	5702	5631	5490	5302	5134	5061	5054	5124	5272	5401	5510	5564
5617	5647	5606	5493	5347	5182	5017	4957	4942	5011	5167	5312	5434

Unit in 0.1 mm

August - September, 1957

Day \ Hour (UT)		0	1	2	3	4	5	6	7	8	9	10
Aug.	25	660	433	329	327	409	587	822	1003	1097	1136	1081
	26	828	607	411	346	379	509	741	947	1091	1153	1158
	27	972	783	578	423	372	411	539	718	911	991	997
	28	798	683	570	426	337	315	392	523	660	768	822
	29	764	723	639	534	412	427	474	563	654	752	835
	30	963	981	959	905	852	819	823	849	884	934	1008
	31	883	936	965	975	955	921	901	896	903	932	984
Sept.	1	762	825	895	954	1002	1045	1076	1105	1133	1161	1213
	2	1146	1288	1400	1496	1567	1636	1664	1672	1669	1665	1659
	3	1463	1507	1579	1689	1818	1937	1971	1931	1866	1812	1747
	4	1336	1384	1445	1543	1647	1755	1807	1824	1803	1700	1628
	5	1281	1277	1335	1419	1539	1625	1709	1771	1749	1689	1582
	6	1079	1009	1043	1154	1291	1437	1539	1615	1634	1587	1513
	7	974	822	782	856	1013	1160	1320	1406	1437	1404	1309
	8	759	601	570	615	703	853	992	1108	1183	1193	1108
	9	930	819	757	789	880	1001	1103	1276	1422	1481	1422
	10	1300	1128	1049	1022	1041	1141	1330	1548	1651	1715	1715
	11	1554	1419	1351	1306	1300	1362	1449	1609	1780	1885	1881
	12	1806	1622	1498	1400	1369	1381	1423	1492	1578	1639	1639
	13	1414	1329	1226	1133	1081	1074	1103	1152	1229	1300	1319
	14	1318	1283	1209	1148	1126	1119	1137	1182	1239	1323	1379
	15	1285	1299	1270	1239	1208	1179	1172	1188	1210	1253	1300
	16	1111	1184	1222	1253	1254	1235	1232	1244	1272	1305	1358
	17	1243	1324	1440	1531	1564	1581	1593	1576	1564	1568	1582
	18	1212	1321	1423	1552	1626	1635	1617	1559	1468	1392	1360
	19	1146	1221	1353	1545	1684	1773	1793	1749	1663	1542	1432
	20	995	1034	1123	1253	1502	1656	1725	1728	1657	1544	1378
	21	899	858	905	1031	1178	1363	1500	1551	1531	1402	1218
	22	888	785	808	901	1035	1178	1344	1462	1487	1388	1208
	23	931	771	710	777	915	1067	1209	1381	1502	1450	1307
	24	1172	1037	960	913	969	1069	1207	1370	1491	1529	1417
	25	1253	1099	996	937	950	1012	1137	1271	1423	1510	1464
	26	1324	1204	1111	1040	1012	1022	1077	1172	1296	1369	1392
	27	1268	1200	1121	1054	1001	984	1009	1059	1117	1168	1177

Sensitivity 2.5771 μgal/mm

Station : Matsushiro

11	12	13	14	15	16	17	18	19	20	21	22	23
987	831	636	490	436	511	704	891	1046	1147	1179	1131	1011
1073	930	736	552	429	424	519	714	909	1063	1148	1150	1097
940	799	575	350	213	115	148	283	470	651	765	852	857
813	747	627	449	275	158	122	154	295	453	627	719	762
860	843	768	670	548	421	345	337	416	539	682	808	893
1055	1055	965	863	761	649	575	518	504	530	605	705	792
1024	1038	1005	921	835	759	677	599	554	541	562	615	685
1279	1334	1355	1373	1355	1304	1241	1140	1049	982	967	985	1045
1669	1687	1734	1766	1796	1787	1735	1668	1609	1548	1496	1459	1446
1707	1681	1685	1725	1773	1807	1803	1745	1681	1588	1502	1435	1367
1569	1537	1546	1580	1641	1694	1745	1764	1745	1651	1557	1461	1345
1506	1430	1387	1403	1448	1510	1567	1607	1600	1559	1474	1348	1201
1405	1298	1218	1203	1249	1345	1419	1493	1536	1523	1447	1315	1158
1179	984	861	811	853	942	1037	1125	1205	1230	1142	1038	911
1012	905	792	729	751	832	947	1073	1214	1329	1351	1229	1059
1280	1119	1015	948	922	980	1077	1227	1438	1566	1611	1581	1491
1620	1503	1297	1140	1072	1080	1178	1375	1568	1702	1787	1797	1696
1821	1621	1460	1347	1282	1263	1309	1397	1537	1740	1878	1945	1902
1562	1434	1306	1179	1007	918	922	1001	1147	1284	1376	1447	1453
1290	1197	1087	984	864	778	749	787	870	984	1108	1213	1290
1356	1298	1213	1113	1026	930	860	851	895	978	1072	1158	1227
1303	1269	1201	1111	1025	934	833	778	760	794	867	964	1038
1404	1432	1411	1370	1299	1213	1138	1076	1038	1024	1031	1083	1164
1596	1620	1633	1635	1590	1522	1434	1294	1224	1154	1135	1132	1156
1351	1366	1413	1463	1524	1546	1533	1455	1342	1252	1173	1132	1114
1322	1303	1330	1401	1501	1571	1616	1600	1509	1356	1193	1100	1033
1256	1166	1156	1194	1303	1430	1573	1603	1576	1480	1289	1121	1008
1088	983	931	952	1025	1135	1272	1421	1506	1501	1345	1183	1033
1042	888	763	707	769	917	1082	1209	1361	1439	1383	1239	1088
1143	978	836	731	731	840	1014	1188	1394	1604	1643	1594	1388
1184	1017	827	661	569	615	731	940	1123	1283	1426	1474	1413
1292	1114	953	764	620	593	630	824	1008	1156	1320	1442	1444
1300	1181	1017	855	676	557	548	658	830	993	1119	1239	1303
1156	1080	969	815	631	491	417	424	551	705	892	1009	1089

Unit in 0.1 mm

Gravity

October – November, 1957

Day \ Hour (UT)		0	1	2	3	4	5	6	7	8	9	10
Oct.	8	1403	1223	1179	1227	1371	1514	1705	1787	1830	1820	1657
	9	1244	1095	990	980	1060	1210	1344	1464	1497	1481	1419
	10	1261	1147	1034	995	1084	1198	1353	1477	1550	1580	1540
	11	1465	1403	1345	1293	1303	1352	1442	1545	1660	1733	1692
	12	1420	1356	1277	1216	1195	1205	1281	1383	1456	1501	1497
	13	1347	1271	1141	1021	869	861	888	966	1064	1156	1181
	14	878	921	877	795	700	676	719	813	943	1013	1039
	15	650	807	863	866	853	843	856	888	939	986	1023
	16	667	886	988	1048	1049	1042	1027	1009	986	971	956
	17	391	535	732	926	1029	1036	1021	980	916	809	734
	18	1169	1373	1641	1925	2196	2388	2430	2531	2489	2430	2367
	19	2181	2245	2448	2677	2893	3040	3101	3078	3004	2918	2803
	20	2229	2207	2287	2513	2745	2908	2974	2978	2930	2750	2467
	21	2058	2009	2035	2163	2374	2600	2858	2900	2878	2738	2416
	22	2201	2101	2123	2234	2369	2514	2699	2879	2893	2702	2479
	23	2132	1962	1829	1873	1977	2167	2350	2458	2512	2459	2316
	24	1927	1772	1652	1613	1652	1786	1962	2089	2176	2160	2089
	25	1817	1732	1616	1527	1484	1536	1647	1749	1838	1867	1827
	26	1608	1559	1479	1409	1344	1343	1387	1457	1537	1588	1572
	27	1132	1110	1061	999	946	932	953	1022	1090	1132	1150
	28	1110	1144	1151	1134	1115	1094	1096	1116	1161	1195	1214
	29	1108	1171	1208	1224	1228	1220	1214	1204	1215	1235	1246
	30	1214	1324	1423	1497	1542	1548	1530	1457	1402	1365	1340
	31	1417	1559	1677	1775	1829	1867	1871	1847	1818	1778	1757
Nov.	1	1817	1915	2083	2236	2337	2392	2399	2366	2286	2164	2049
	2	1799	1848	1974	2142	2277	2352	2367	2322	2252	2132	1972
	3	2054	2094	2225	2350	2458	2547	2595	2554	2477	2362	2188
	4	2013	2006	2070	2183	2332	2442	2511	2522	2468	2342	2146
	5	2075	2033	2057	2160	2292	2408	2500	2522	2489	2387	2203
	6	2039	1932	1922	1991	2123	2272	2383	2422	2413	2334	2142
	7	2025	1964	1939	1969	2062	2198	2397	2527	2575	2528	2364
	8	2501	2423	2342	2349	2484	2624	2772	2953	3025	3003	2899
	9	2650	2520	2435	2388	2393	2453	2558	2695	2789	2797	2682
	10	2416	2335	2262	2195	2159	2217	2297	2382	2456	2524	2537

Sensitivity : 2.4776 μgal/mm

Station : Omaezaki

11	12	13	14	15	16	17	18	19	20	21	22	23
1428	1157	987	871	814	936	1101	1278	1417	1509	1517	1469	1386
1251	1031	745	606	549	599	707	958	1191	1342	1396	1399	1347
1427	1284	1102	865	734	724	816	1016	1254	1404	1514	1568	1543
1567	1422	1244	1031	805	724	733	853	1072	1246	1393	1436	1443
1435	1316	1126	883	671	592	576	626	740	946	1143	1277	1350
1115	911	700	521	375	241	174	170	200	298	439	582	731
1026	956	754	528	336	205	154	117	123	152	225	336	496
1037	1039	978	880	706	511	384	272	223	216	255	352	494
944	951	958	926	840	684	536	403	299	220	186	199	262
708	729	841	950	1000	1026	1029	1026	1001	979	975	997	1056
2315	2342	2419	2490	2559	2650	2712	2692	2586	2391	2222	2167	2162
2661	2548	2505	2585	2752	2884	2953	2967	2928	2843	2688	2468	2322
2253	2100	2017	2028	2136	2332	2564	2848	2887	2845	2718	2449	2208
2074	1897	1812	1808	1918	2097	2285	2436	2623	2627	2542	2419	2291
2254	1955	1681	1587	1572	1688	1882	2167	2352	2471	2472	2412	2291
2049	1682	1427	1217	1149	1186	1337	1565	1828	2007	2089	2093	2038
1942	1679	1363	1139	1033	1007	1088	1276	1522	1715	1840	1897	1896
1693	1486	1212	872	708	649	698	820	1004	1237	1448	1570	1619
1498	1318	1089	837	616	454	389	415	501	660	840	1013	1096
1109	1042	893	693	523	394	325	322	401	502	687	872	1023
1206	1173	1104	1004	873	753	621	563	564	640	751	893	1010
1260	1260	1241	1196	1128	1066	997	934	915	935	995	1063	1132
1328	1336	1344	1340	1319	1287	1247	1200	1176	1159	1170	1213	1280
1750	1768	1787	1807	1827	1842	1839	1816	1780	1732	1705	1709	1740
1963	1940	1953	2000	2062	2116	2130	2114	2057	1973	1876	1817	1792
1870	1845	1860	1948	2079	2244	2337	2382	2370	2329	2252	2169	2073
2065	1924	1892	1929	2053	2202	2317	2389	2407	2372	2305	2197	2082
1966	1804	1752	1802	1905	2069	2260	2379	2443	2442	2393	2284	2175
1992	1763	1652	1619	1681	1815	2054	2232	2357	2402	2378	2299	2170
1861	1642	1474	1375	1412	1570	1773	1969	2113	2252	2323	2267	2152
2115	1935	1753	1629	1600	1678	1845	2069	2319	2545	2620	2639	2586
2662	2412	2222	2049	1945	1988	2092	2262	2430	2612	2793	2848	2769
2495	2280	2045	1792	1623	1572	1642	1763	2008	2220	2361	2437	2453
2457	2238	2008	1719	1470	1357	1335	1414	1574	1864	2027	2156	2204

Unit in 0.1 mm

January - February, 1958

Day \ Hour (UT)		0	1	2	3	4	5	6	7	8	9	10
Jan.	18	2229	2179	2177	2248	2362	2491	2620	2725	2732	2633	2449
	19	2832	2765	2725	2730	2794	2874	2976	3081	3100	3046	2952
	20	2996	2906	2846	2823	2824	2896	2985	3100	3183	3181	3095
	21	3006	2909	2827	2758	2724	2775	2851	2931	3007	3053	3022
	22	2859	2770	2625	2468	2386	2387	2473	2594	2706	2805	2816
	23	2679	2617	2512	2383	2285	2232	2302	2421	2531	2595	2644
	24	2806	2795	2716	2635	2550	2500	2525	2576	2649	2734	2808
	25	3165	3182	3125	2966	2827	2760	2718	2727	2794	2895	3017
	26	3188	3182	3148	3069	2978	2881	2807	2757	2768	2819	2879
	27	2957	2882	2782	2663	2531	2382	2235	2130	2064	2042	2060
	28	2193	2223	2235	2201	2126	2045	1938	1843	1746	1694	1681
	29	2007	2041	2054	2066	2035	1965	1850	1731	1588	1489	1410
	30	1746	1794	1838	1884	1916	1886	1834	1724	1563	1413	1313
	31	1698	1727	1802	1892	1941	1986	1973	1901	1759	1606	1473
Feb.	1	1828	1825	1901	2029	2162	2224	2280	2255	2173	1973	1780
	2	1959	1884	1823	1842	1915	2005	2098	2117	2068	1895	1641
	3	1541	1398	1297	1263	1303	1418	1533	1602	1606	1530	1339
	4	1376	1272	1131	1101	1135	1228	1338	1461	1565	1599	1519
	5	1509	1346	1223	1116	1105	1178	1310	1454	1594	1677	1679
	6	1556	1380	1169	1026	954	961	1074	1245	1422	1579	1641
	7	1710	1564	1388	1230	1109	1046	1098	1194	1331	1468	1588
	8	1773	1668	1510	1346	1196	1067	1034	1081	1170	1276	1374
	9	1507	1474	1375	1226	1087	960	865	843	856	939	1055
	10	1299	1342	1289	1216	1101	998	903	833	782	779	829
	11	1242	1286	1288	1267	1181	1097	994	866	766	691	680
	12	1077	1103	1133	1134	1127	1093	1021	922	802	711	643
	13	1111	1116	1143	1178	1202	1211	1181	1136	1069	991	886
	14	1228	1269	1324	1413	1592	1684	1698	1639	1539	1405	1238
	15	1520	1497	1509	1558	1651	1757	1829	1825	1756	1618	1440
	16	1470	1420	1417	1460	1515	1617	1717	1788	1746	1630	1475
	17	1367	1294	1245	1232	1295	1413	1525	1635	1672	1635	1490
	18	1339	1241	1166	1126	1197	1326	1471	1586	1686	1663	1596
	19	1470	1325	1207	1121	1139	1229	1366	1508	1645	1642	1586
	20	1156	1006	837	699	645	679	788	933	1072	1156	1164

Sensitivity : 2.5141 μgal/mm

Station : Shionomisaki

11	12	13	14	15	16	17	18	19	20	21	22	23
2206	2067	1939	1891	1881	1968	2156	2432	2682	2837	2915	2923	2890
2806	2578	2354	2192	2133	2197	2322	2587	2826	2953	3050	3071	3046
2960	2816	2590	2383	2235	2227	2326	2552	2777	2915	3017	3085	3070
2927	2792	2586	2326	2168	2078	2115	2233	2436	2685	2822	2896	2896
2747	2596	2389	2207	2004	1907	1907	1998	2177	2372	2552	2642	2683
2637	2581	2477	2313	2152	2002	1984	2056	2232	2419	2581	2677	2775
2848	2816	2750	2686	2584	2525	2473	2498	2575	2658	2766	2896	3048
3092	3117	3111	3047	2972	2869	2800	2765	2784	2882	2989	3101	3164
2922	2949	2948	2904	2813	2739	2655	2605	2646	2771	2911	3030	3033
2098	2130	2149	2149	2130	2077	2051	2018	1993	2000	2037	2080	2135
1693	1747	1802	1868	1923	1947	1946	1938	1932	1923	1919	1944	1977
1363	1391	1456	1523	1623	1704	1757	1808	1803	1791	1760	1721	1728
1213	1189	1224	1329	1457	1565	1674	1766	1803	1815	1783	1741	1703
1341	1251	1241	1301	1400	1564	1721	1878	1998	2042	2024	1956	1879
1607	1454	1374	1380	1474	1641	1811	2013	2183	2268	2262	2185	2073
1369	1159	993	905	1016	1221	1413	1569	1731	1828	1830	1784	1677
1078	789	582	441	398	476	669	939	1214	1396	1524	1547	1491
1341	1151	920	701	592	601	749	991	1234	1433	1608	1666	1625
1584	1384	1106	886	712	647	704	844	1042	1321	1524	1624	1639
1612	1501	1314	1077	914	813	789	885	1046	1279	1521	1674	1756
1654	1646	1511	1376	1239	1087	1029	1056	1181	1309	1467	1676	1768
1464	1486	1466	1391	1272	1161	1037	977	999	1068	1160	1283	1442
1139	1212	1237	1236	1196	1132	1054	986	968	979	1033	1111	1193
910	981	1067	1118	1136	1131	1112	1082	1065	1079	1089	1128	1192
716	761	846	916	992	1038	1059	1052	1048	1036	1028	1031	1040
600	646	728	840	925	1030	1101	1144	1143	1136	1121	1118	1111
768	685	743	861	1000	1101	1181	1259	1318	1345	1300	1261	1233
1112	1002	968	1005	1103	1244	1410	1559	1656	1704	1695	1641	1563
1288	1157	1021	1003	1061	1177	1340	1509	1636	1723	1719	1670	1552
1298	1108	951	849	869	987	1152	1323	1463	1570	1601	1560	1475
1327	1125	899	774	736	793	972	1185	1365	1476	1562	1538	1460
1464	1277	1079	912	876	880	1014	1224	1419	1553	1665	1678	1584
1470	1280	1107	914	762	710	768	890	1046	1189	1283	1308	1258
1116	943	724	536	388	339	371	448	610	795	966	1037	1016

Unit in 0.1 mm

Gravity

March - May, 1958

Day \ Hour (UT)	0	1	2	3	4	5	6	7	8	9	10
Mar. 31	1892	1882	1920	1995	2121	2243	2315	2321	2281	2162	2003
Apr. 1	1677	1523	1510	1621	1849	2079	2213	2241	2187	2098	1931
2	1138	968	861	870	1037	1218	1488	1600	1667	1648	1518
3	650	377	207	130	194	390	663	861	1012	1096	1047
4	641	423	132	35	52	212	456	736	1060	1231	1310
5	917	673	461	261	196	257	491	757	1031	1241	1416
6	1141	959	720	474	308	256	325	544	814	1032	1242
7	1283	1121	926	753	581	415	395	542	702	921	1083
8	1175	1107	990	852	710	612	543	583	674	809	950
9	1218	1185	1085	983	830	698	582	494	479	607	757
10	1247	1267	1249	1200	1136	1064	972	917	912	929	967
11	1209	1244	1289	1329	1318	1277	1211	1124	1058	1029	1027
12	1324	1359	1380	1408	1446	1470	1475	1445	1383	1312	1243
13	1560	1573	1626	1738	1870	2033	2077	2049	2004	1901	1795
14	2059	2043	2102	2230	2409	2558	2675	2789	2775	2677	2558
15	2255	2162	2149	2257	2393	2535	2697	2756	2790	2748	2666
16	2167	2056	1951	2027	2176	2344	2483	2633	2752	2749	2629
17	1683	1488	1368	1343	1493	1688	1880	2036	2209	2217	2147
18	1477	1248	1063	1027	1097	1274	1452	1646	1847	1918	1909
19	1028	841	646	562	589	717	917	1125	1357	1554	1633
20	1333	1157	988	837	806	890	1051	1257	1549	1742	1891
21	1716	1534	1347	1160	1063	1073	1213	1406	1621	1812	1953
22	1623	1450	1267	1072	909	869	900	1016	1231	1422	1562
23	1442	1335	1152	912	733	664	665	738	874	1008	1223
24	1633	1572	1476	1342	1210	1058	984	1040	1136	1282	1455
25	1685	1681	1628	1561	1412	1298	1207	1155	1143	1183	1313
26	1458	1515	1539	1496	1429	1377	1283	1202	1162	1179	1222
27	1479	1530	1596	1644	1667	1638	1601	1551	1492	1423	1367
28	2223	2357	2475	2594	2743	2877	2951	2950	2870	2698	2584
29	2743	2800	2875	2995	3123	3294	3433	3445	3391	3284	3139
30	2984	2923	2969	3114	3306	3480	3641	3759	3779	3635	3479
May 1	2762	2606	2585	2664	2842	3111	3314	3463	3539	3469	3339
2	2248	2061	1908	1893	1987	2249	2535	2728	2902	3011	2972
3	2582	2362	2087	1997	2066	2330	2585	2880	3148	3339	3354

Sensitivity 2.5087 μgal/mm

Station : Naze

11	12	13	14	15	16	17	18	19	20	21	22	23
1811	1640	1577	1635	1756	1906	2093	2232	2265	2251	2148	1997	1802
1688	1442	1257	1210	1261	1411	1611	1812	1941	1961	1889	1705	1443
1262	954	712	541	505	606	772	957	1159	1241	1192	1044	863
873	655	395	200	105	148	278	551	775	960	1031	984	841
1244	1063	851	652	506	455	504	685	875	1083	1215	1237	1126
1435	1366	1148	944	791	658	643	732	903	1068	1217	1325	1301
1411	1403	1311	1126	965	863	824	842	917	1034	1193	1331	1370
1242	1358	1338	1208	1081	960	874	853	866	920	1017	1109	1189
1113	1264	1346	1337	1257	1156	1090	1025	992	1006	1052	1116	1186
875	996	1075	1128	1154	1145	1100	1055	1028	1037	1046	1101	1172
1030	1112	1219	1340	1404	1428	1425	1385	1318	1265	1203	1167	1175
1050	1127	1229	1345	1421	1476	1499	1504	1473	1426	1382	1344	1316
1216	1236	1304	1395	1504	1634	1725	1787	1819	1771	1720	1627	1569
1724	1681	1710	1795	1960	2092	2261	2394	2470	2448	2340	2254	2157
2454	2374	2318	2317	2366	2463	2583	2679	2728	2706	2636	2526	2372
2538	2411	2305	2259	2300	2424	2526	2638	2697	2704	2648	2539	2364
2466	2295	2106	2001	1954	2032	2165	2296	2385	2413	2364	2208	1975
2000	1834	1664	1568	1496	1537	1635	1768	1875	1947	1933	1850	1684
1808	1627	1443	1274	1179	1145	1218	1324	1440	1522	1533	1462	1273
1588	1466	1287	1131	1037	1029	1077	1194	1373	1554	1640	1638	1542
1874	1803	1710	1571	1464	1386	1429	1516	1651	1782	1928	1986	1861
2043	1985	1853	1712	1601	1495	1453	1484	1576	1665	1743	1783	1741
1643	1651	1589	1470	1346	1221	1142	1141	1203	1318	1394	1462	1468
1399	1494	1508	1491	1433	1354	1290	1261	1313	1408	1496	1572	1630
1593	1682	1724	1710	1682	1625	1559	1506	1487	1509	1561	1628	1666
1448	1552	1626	1672	1650	1609	1535	1457	1382	1333	1332	1347	1390
1323	1453	1564	1635	1697	1730	1716	1656	1578	1537	1500	1463	1460
1379	1464	1597	1752	1964	2153	2253	2282	2250	2192	2127	2102	2124
2564	2590	2673	2862	2998	3132	3255	3317	3276	3155	2983	2848	2764
2990	2916	2922	3022	3171	3400	3544	3655	3675	3573	3427	3248	3084
3295	3129	3044	3028	3143	3274	3401	3525	3586	3553	3382	3216	3006
3176	2941	2718	2615	2627	2707	2841	3004	3119	3123	2965	2759	2537
2853	2693	2538	2382	2337	2441	2620	2774	2936	3077	3087	2989	2805
3298	3129	2885	2760	2656	2668	2737	2852	3039	3213	3283	3257	3076

Unit in 0.1 mm

June - July, 1958

Day \ Hour (UT)		0	1	2	3	4	5	6	7	8	9	10
June	11	487	553	623	708	800	876	912	936	924	902	882
	12	634	672	752	823	930	1003	1056	1073	1052	1002	963
	13	518	516	586	705	837	952	1036	1101	1104	1072	1015
	14	715	692	721	814	919	1077	1224	1345	1410	1375	1304
	15	631	510	494	545	714	877	1059	1234	1351	1391	1356
	16	900	739	696	743	840	995	1220	1439	1619	1710	1700
	17	1121	947	821	770	835	1006	1190	1367	1554	1710	1738
	18	1289	1118	947	879	915	997	1159	1342	1526	1760	1857
	19	1448	1261	1096	937	865	915	1072	1245	1400	1610	1782
	20	1502	1353	1212	1052	929	886	951	1087	1259	1402	1563
	21	1437	1342	1230	1055	935	843	831	948	1102	1251	1394
	22	1584	1550	1440	1332	1234	1133	1075	1089	1170	1280	1389
	23	1445	1452	1443	1373	1315	1248	1196	1164	1181	1259	1346
	24	1354	1402	1440	1442	1416	1370	1301	1268	1257	1271	1314
	25	1236	1301	1368	1428	1453	1450	1430	1387	1351	1332	1337
	26	1127	1195	1286	1397	1500	1592	1620	1608	1553	1483	1425
	27	1048	1086	1166	1283	1414	1541	1695	1769	1774	1711	1601
	28	985	945	1014	1139	1294	1431	1598	1746	1827	1812	1713
	29	1080	967	950	1041	1207	1365	1562	1776	1878	1907	1870
	30	1205	1052	942	983	1095	1268	1487	1684	1806	1873	1878
July	1	1354	1166	1009	976	1034	1224	1454	1670	1838	1984	2059
	2	1700	1513	1295	1193	1167	1229	1412	1596	1768	1934	2067
	3	1778	1641	1487	1316	1239	1281	1417	1590	1743	1909	2084
	4	1944	1779	1650	1523	1408	1371	1462	1587	1714	1847	1991
	5	1929	1801	1682	1575	1478	1422	1458	1535	1651	1771	1896
	6	1907	1836	1747	1658	1576	1518	1499	1537	1601	1691	1785
	7	1785	1779	1739	1680	1620	1566	1546	1542	1591	1676	1747
	8	1748	1769	1767	1759	1725	1670	1645	1646	1656	1690	1746
	9	1683	1728	1753	1784	1776	1767	1748	1740	1740	1742	1778
	10	1656	1709	1752	1809	1844	1867	1876	1856	1839	1826	1826
	11	1582	1631	1697	1768	1851	1899	1981	1996	1966	1939	1911
	12	1554	1571	1634	1745	1867	1985	2096	2178	2205	2142	2089
	13	1604	1588	1618	1718	1850	2004	2150	2248	2309	2291	2191
	14	1522	1426	1449	1553	1698	1872	2104	2287	2377	2415	2388

Sensitivity 2.5248 μgal/mm

Station : Kyoto (II)

11	12	13	14	15	16	17	18	19	20	21	22	23
879	910	956	1013	1085	1139	1170	1152	1068	961	859	751	676
911	896	923	960	1031	1112	1149	1130	1073	978	847	724	598
950	914	910	953	1012	1100	1215	1235	1218	1144	1025	908	808
1184	1114	1065	1052	1104	1187	1268	1350	1357	1269	1117	961	776
1272	1157	1095	1076	1105	1196	1319	1408	1478	1468	1413	1247	1073
1627	1487	1390	1325	1312	1391	1486	1588	1692	1720	1659	1516	1317
1663	1553	1425	1336	1303	1322	1411	1515	1622	1713	1726	1628	1472
1886	1833	1719	1582	1482	1461	1492	1570	1664	1786	1813	1791	1637
1822	1810	1708	1552	1430	1364	1369	1411	1492	1602	1728	1727	1656
1682	1718	1653	1539	1412	1323	1280	1283	1336	1385	1451	1505	1492
1537	1654	1656	1612	1483	1403	1342	1309	1313	1363	1438	1531	1593
1500	1650	1730	1721	1617	1483	1382	1316	1284	1289	1321	1368	1413
1452	1570	1684	1741	1715	1584	1468	1377	1297	1254	1250	1265	1304
1397	1485	1598	1691	1727	1674	1544	1440	1339	1268	1207	1179	1195
1369	1452	1547	1684	1756	1772	1688	1585	1436	1327	1225	1151	1118
1419	1441	1502	1612	1732	1804	1804	1748	1597	1427	1289	1166	1070
1541	1503	1528	1603	1733	1833	1894	1890	1799	1612	1416	1268	1112
1608	1524	1506	1522	1633	1749	1869	1909	1889	1781	1589	1390	1227
1789	1640	1530	1499	1558	1670	1815	1917	1963	1926	1818	1566	1362
1837	1754	1701	1654	1661	1710	1790	1869	1951	1969	1892	1754	1549
2026	1936	1836	1770	1752	1759	1816	1896	2036	2153	2142	2030	1857
2104	2015	1898	1788	1731	1725	1756	1822	1954	2098	2156	2098	1947
2182	2152	2073	1919	1803	1760	1768	1809	1903	2023	2155	2154	2085
2120	2127	2082	1938	1834	1763	1726	1744	1783	1853	1933	1992	2003
2008	2078	2064	1987	1886	1788	1743	1730	1730	1767	1825	1883	1922
1873	1938	1946	1916	1829	1754	1691	1654	1630	1642	1676	1723	1765
1837	1910	1958	1966	1914	1835	1754	1702	1656	1646	1666	1694	1721
1827	1893	1940	1947	1939	1886	1813	1746	1687	1641	1617	1621	1645
1816	1863	1931	1971	1986	1963	1901	1814	1742	1682	1631	1606	1622
1845	1884	1940	1989	2059	2082	2037	1945	1844	1737	1663	1616	1575
1886	1924	1958	2034	2117	2166	2165	2087	1999	1877	1773	1652	1583
2048	2038	2054	2095	2189	2276	2337	2310	2226	2073	1932	1818	1695
2089	2029	2023	2049	2118	2198	2310	2366	2317	2196	2005	1851	1685
2356	2312	2276	2254	2276	2326	2399	2454	2458	2422	2316	2192	1983

Unit in 0.1 mm

Gravity

August – September, 1958

Day \ Hour (UT)		0	1	2	3	4	5	6	7	8	9	10
Aug.	1	2386	2268	2190	2206	2268	2399	2599	2793	2938	3028	3064
	2	2920	2807	2668	2596	2601	2675	2800	2933	3026	3101	3148
	3	2915	2763	2681	2608	2584	2616	2677	2755	2836	2895	2932
	4	2814	2747	2666	2573	2555	2579	2638	2726	2818	2898	2943
	5	2902	2876	2838	2806	2768	2774	2808	2866	2928	3004	3083
	6	3068	3064	3042	3030	3022	3029	3058	3111	3215	3341	3421
	7	3367	3412	3420	3432	3441	3442	3454	3472	3502	3538	3573
	8	3336	3388	3436	3459	3478	3501	3503	3515	3535	3551	3561
	9	3102	3190	3281	3363	3406	3439	3444	3449	3455	3456	3465
	10	2939	3004	3101	3237	3338	3421	3458	3461	3451	3426	3401
	11	2618	2676	2809	2920	3068	3161	3199	3235	3231	3209	3188
	12	2479	2494	2562	2684	2846	3001	3124	3194	3181	3135	3086
	13	2419	2370	2424	2510	2667	2879	3060	3146	3168	3166	3118
	14	2498	2419	2410	2481	2626	2860	3069	3199	3254	3262	3232
	15	2814	2631	2572	2612	2761	2970	3169	3291	3393	3442	3405
	16	3166	3041	2945	2910	2959	3091	3245	3413	3597	3692	3704
	17	3514	3348	3212	3178	3192	3270	3452	3656	3842	3930	3962
	18	3915	3831	3746	3663	3629	3660	3761	3862	3972	4072	4153
	19	4095	4045	3993	3943	3908	3912	3949	4030	4129	4232	4334
	20	4292	4330	4332	4309	4273	4259	4285	4363	4481	4575	4636
	21	4529	4607	4641	4657	4654	4653	4656	4662	4709	4777	4832
	22	4456	4548	4629	4704	4746	4769	4770	4769	4781	4791	4797
	23	4343	4434	4533	4629	4712	4761	4773	4770	4766	4750	4750
	24	4153	4233	4324	4452	4580	4672	4727	4728	4710	4687	4660
	25	4097	4126	4195	4275	4433	4592	4694	4755	4745	4712	4672
	26	4126	4132	4206	4340	4489	4633	4738	4804	4833	4817	4757
	27	4276	4268	4308	4416	4597	4759	4878	4962	4981	4962	4921
	28	4592	4508	4498	4579	4712	4862	4992	5079	5162	5160	5116
	29	4899	4825	4802	4833	4899	5015	5162	5342	5465	5484	5455
	30	5133	5025	4946	4931	4996	5127	5309	5488	5594	5654	5652
	31	5591	5463	5366	5351	5391	5470	5606	5732	5824	5873	5862
Sept.	1	5715	5629	5531	5473	5452	5530	5637	5734	5815	5863	5869
	2	5696	5603	5523	5463	5440	5479	5554	5664	5758	5833	5844
	3	5702	5666	5605	5549	5504	5521	5579	5658	5722	5768	5802

Sensitivity : 2.7806 μgal/mm

Station : Nemuro

11	12	13	14	15	16	17	18	19	20	21	22	23
3046	3005	2954	2891	2866	2887	2940	3017	3086	3130	3141	3106	3032
3139	3095	3022	2951	2893	2880	2891	2928	2996	3049	3081	3084	3011
2933	2898	2841	2763	2701	2657	2652	2692	2746	2812	2843	2868	2856
2970	2949	2901	2848	2784	2708	2681	2694	2737	2799	2856	2905	2914
3113	3106	3058	2995	2934	2887	2860	2854	2863	2902	2950	2998	3044
3478	3497	3487	3436	3337	3247	3123	3085	3082	3088	3136	3210	3308
3608	3615	3614	3599	3554	3511	3436	3341	3270	3218	3206	3227	3273
3568	3576	3583	3566	3531	3486	3422	3342	3238	3133	3070	3041	3052
3475	3500	3520	3532	3528	3483	3419	3326	3215	3083	2964	2908	2908
3391	3393	3406	3431	3447	3437	3399	3318	3210	3034	2868	2720	2617
3144	3125	3134	3156	3198	3209	3212	3170	3102	2962	2826	2652	2531
3028	2988	2989	3017	3076	3130	3171	3176	3133	3036	2874	2663	2502
3062	3002	2957	2973	3029	3107	3187	3218	3208	3158	3040	2868	2656
3166	3093	3024	3026	3057	3131	3230	3292	3341	3332	3278	3178	3010
3330	3279	3214	3146	3146	3197	3284	3361	3483	3529	3488	3408	3286
3642	3471	3312	3217	3202	3210	3295	3431	3601	3724	3768	3746	3648
3930	3863	3766	3672	3580	3543	3590	3691	3819	3902	3982	4010	3986
4155	4086	3990	3879	3792	3726	3711	3736	3838	3930	4015	4066	4096
4349	4314	4226	4106	4012	3925	3864	3862	3887	3967	4061	4159	4235
4687	4673	4619	4519	4401	4287	4197	4140	4128	4172	4227	4321	4431
4851	4858	4854	4777	4675	4572	4465	4360	4289	4254	4263	4294	4362
4804	4812	4824	4821	4779	4709	4613	4486	4387	4307	4266	4253	4280
4753	4756	4761	4766	4761	4739	4660	4542	4412	4281	4162	4097	4091
4657	4667	4678	4721	4743	4758	4732	4653	4552	4434	4292	4182	4113
4632	4620	4621	4667	4721	4766	4772	474~~6~~9	4685	4575	4436	4287	4202
4701	4661	4656	4694	4768	4826	4876	4890	4879	4817	4688	4561	4408
4874	4818	4790	4797	4833	4905	4987	5042	5043	5008	4948	4837	4723
5038	4969	4936	4927	4964	5033	5118	5238	5307	5335	5259	5127	4999
5354	5234	5133	5065	5084	5162	5256	5403	5505	5541	5521	5435	5304
5621	5518	5382	5282	5261	5325	5451	5612	5741	5802	5837	5806	5713
5812	5716	5619	5497	5440	5445	5508	5633	5752	5822	5880	5853	5801
5843	5730	5562	5426	5348	5327	5352	5453	5583	5678	5744	5762	5742
5830	5754	5634	5516	5402	5345	5335	5392	5499	5598	5684	5737	5736
5792	5737	5655	5545	5409	5316	5276	5277	5334	5406	5495	5584	5627

Unit in 0.1 mm

Gravity

September - October, 1958

Day \ Hour (UT)		0	1	2	3	4	5	6	7	8	9	10
Sept.	15	727	619	517	461	465	530	649	776	941	1064	1050
	16	965	828	719	651	626	654	723	850	1022	1133	1149
	17	1021	960	879	810	761	733	788	883	1032	1126	1169
	18	1069	1101	1076	1025	977	935	907	932	990	1079	1160
	19	1121	1178	1210	1226	1219	1207	1200	1206	1225	1247	1285
	20	1165	1242	1298	1348	1394	1408	1400	1377	1374	1378	1393
	21	1162	1244	1324	1392	1469	1520	1550	1539	1492	1440	1421
	22	1180	1239	1309	1419	1531	1633	1672	1660	1605	1531	1459
	23	1164	1197	1272	1362	1484	1603	1670	1689	1665	1614	1540
	24	1205	1226	1286	1385	1483	1593	1684	1724	1708	1654	1593
	25	1303	1274	1314	1400	1524	1630	1728	1787	1806	1764	1682
	26	1403	1316	1319	1373	1514	1610	1712	1769	1787	1751	1683
	27	1561	1486	1470	1493	1568	1664	1772	1875	1932	1884	1801
	28	1702	1604	1572	1583	1649	1734	1862	2014	2118	2086	1996
	29	1805	1700	1642	1619	1652	1740	1876	1987	2075	2097	2032
	30	1918	1781	1697	1656	1666	1720	1834	1967	2071	2114	2081
Oct.	1	2026	1935	1822	1774	1766	1802	1877	1999	2077	2132	2137
	2	2134	2066	2009	1946	1916	1901	1942	2030	2110	2170	2189
	3	2168	2148	2110	2068	2038	2046	2088	2148	2209	2270	2298
	4	2231	2255	2248	2246	2238	2238	2241	2262	2298	2323	2344
	5	2282	2318	2343	2353	2360	2361	2350	2348	2354	2370	2378
	6	2274	2332	2404	2443	2455	2459	2448	2436	2430	2424	2421
	7	2229	2323	2410	2468	2509	2535	2543	2530	2488	2461	2440
	8	2267	2352	2485	2622	2705	2755	2757	2722	2657	2572	2486
	9	2283	2323	2413	2585	2761	2879	2938	2917	2842	2721	2594
	10	2260	2263	2350	2511	2694	2851	2935	2950	2896	2792	2625
	11	2428	2390	2430	2552	2710	2883	2999	3037	3022	2932	2793
	12	2709	2588	2570	2636	2771	2919	3029	3109	3113	3073	2961
	13	2892	2789	2701	2694	2791	2903	3022	3098	3143	3119	3031
	14	3035	2963	2868	2819	2840	2917	3010	3088	3157	3161	3119
	15	3103	3047	2970	2915	2901	2922	2993	3069	3134	3170	3135
	16	3097	3071	3007	2961	2926	2929	2962	3016	3062	3101	3107
	17	3107	3119	3108	3077	3054	3052	3061	3083	3112	3145	3167
	18	3137	3193	3209	3215	3202	3182	3172	3185	3202	3222	3242

Sensitivity 2.7037 μgal/mm

Station : Mizusawa

11	12	13	14	15	16	17	18	19	20	21	22	23
949	760	615	479	392	355	399	517	627	769	905	1011	1021
1098	951	743	612	498	424	415	463	569	687	805	932	1012
1179	1099	977	778	658	570	513	519	558	641	754	854	999
1193	1181	1121	990	837	733	670	644	644	675	737	845	988
1322	1328	1320	1271	1217	1137	1059	1003	952	929	955	1021	1091
1410	1438	1440	1432	1400	1359	1295	1243	1180	1121	1087	1087	1115
1419	1439	1469	1479	1479	1468	1431	1379	1322	1259	1200	1161	1151
1418	1418	1434	1484	1522	1569	1578	1545	1486	1389	1277	1202	1162
1480	1449	1454	1499	1567	1621	1662	1665	1640	1580	1462	1358	1240
1538	1470	1453	1488	1545	1613	1669	1724	1731	1685	1611	1508	1403
1586	1484	1443	1461	1510	1585	1670	1739	1797	1776	1713	1625	1522
1592	1486	1423	1402	1461	1540	1659	1752	1837	1865	1833	1748	1653
1690	1573	1493	1451	1464	1544	1646	1763	1894	1983	2002	1936	1795
1829	1712	1618	1553	1529	1572	1661	1792	1932	2072	2117	2068	1944
1922	1731	1585	1481	1440	1472	1546	1679	1837	1982	2061	2091	2030
1989	1840	1679	1530	1457	1450	1493	1589	1740	1914	2046	2083	2088
2087	1957	1781	1648	1546	1502	1512	1599	1712	1841	2010	2092	2149
2159	2068	1906	1737	1641	1565	1553	1588	1667	1763	1899	2029	2124
2261	2209	2116	1999	1888	1786	1738	1722	1770	1852	1978	2078	2164
2353	2338	2294	2211	2120	2022	1915	1865	1875	1924	2001	2088	2178
2387	2389	2377	2346	2304	2248	2158	2091	2038	2021	2039	2107	2174
2418	2425	2428	2425	2410	2378	2329	2269	2197	2138	2095	2100	2149
2428	2434	2451	2487	2509	2517	2503	2452	2399	2338	2265	2229	2228
2442	2442	2499	2575	2666	2739	2792	2772	2681	2513	2382	2322	2283
2466	2414	2405	2473	2601	2733	2812	2864	2846	2762	2600	2440	2317
2447	2342	2318	2365	2488	2670	2830	2963	2994	2957	2866	2745	2587
2595	2409	2323	2311	2416	2607	2810	2962	3050	3091	3070	2986	2836
2801	2580	2411	2354	2375	2493	2709	2907	3042	3119	3129	3098	3012
2895	2681	2494	2318	2299	2361	2518	2742	2948	3068	3140	3149	3111
3019	2850	2645	2450	2339	2322	2402	2580	2771	2965	3083	3135	3135
3055	2946	2774	2601	2425	2366	2369	2453	2615	2805	2948	3031	3078
3079	3019	2892	2746	2598	2462	2418	2461	2568	2703	2876	2986	3058
3163	3112	3058	2984	2885	2773	2701	2682	2712	2800	2895	3000	3072
3245	3229	3195	3155	3094	3022	2961	2919	2892	2907	2952	3012	3080

Unit in 0.1 mm

Gravity

October - December, 1958

Day		Hour (UT) 0	1	2	3	4	5	6	7	8	9	10
Oct.	30	2617	2518	2450	2415	2426	2476	2558	2618	2666	2653	2601
	31	2050	1968	1895	1838	1830	1888	1970	2039	2087	2104	2052
Nov.	1	1460	1429	1384	1324	1292	1301	1355	1413	1445	1451	1440
	2	1135	1196	1225	1208	1191	1205	1228	1271	1341	1428	1498
	3	1419	1465	1488	1499	1494	1486	1478	1488	1506	1542	1569
	4	1700	1851	1953	1992	2000	1977	1949	1912	1892	1879	1869
	5	1519	1624	1769	1911	1966	1953	1869	1748	1601	1534	1486
	6	1250	1354	1446	1527	1590	1613	1608	1546	1454	1375	1296
	7	758	881	1121	1316	1424	1463	1458	1381	1250	1078	842
	8	557	636	762	901	1064	1267	1374	1382	1284	1095	908
	9	1031	1020	1054	1142	1315	1599	1808	1848	1737	1567	1388
	10	1427	1379	1382	1435	1583	1817	1979	2007	1983	1833	1583
	11	1254	1146	1038	1028	1097	1218	1305	1364	1362	1293	1127
	12	979	849	749	703	772	890	1007	1074	1110	1093	1033
	13	1226	1162	1115	1090	1107	1166	1262	1419	1567	1610	1534
	14	1539	1515	1460	1395	1359	1344	1374	1430	1492	1500	1461
	15	1233	1250	1241	1212	1182	1186	1227	1285	1350	1416	1472
	16	2098	2189	2258	2255	2220	2225	2247	2304	2386	2464	2552
	17	2609	2740	2831	2864	2861	2845	2819	2783	2765	2778	2782
	18	2639	2695	2754	2806	2815	2796	2757	2699	2671	2653	2644
	19	2738	2829	2960	3088	3152	3143	3089	2961	2821	2734	2678
	20	2528	2598	2676	2768	2873	2954	2947	2871	2766	2700	2645
	21	2758	2808	2914	3086	3267	3345	3354	3313	3185	2958	2854
	22	2960	2998	3108	3314	3481	3584	3653	3632	3547	3445	3349
	23	3195	3168	3206	3292	3396	3447	3485	3475	3413	3285	3053
	24	2752	2735	2790	2866	3020	3143	3230	3278	3231	3083	2846
	25	2996	2868	2845	2885	3004	3132	3203	3220	3217	3133	2928
	26	2918	2820	2798	2842	2912	2994	3079	3107	3096	3027	2896
	27	2941	2884	2887	2937	3040	3208	3309	3372	3406	3362	3194
	28	2775	2711	2665	2643	2663	2717	2785	2862	2933	2929	2869
	29	2856	2837	2803	2767	2763	2795	2877	3041	3175	3245	3216
	30	3110	3066	2966	2891	2868	2879	2924	3026	3146	3255	3305
Dec.	1	3528	3573	3561	3519	3496	3510	3535	3586	3652	3710	3733
	2	3451	3473	3474	3434	3390	3359	3341	3329	3326	3337	3335

Sensitivity - 2.7383 μgal/mm

Station : Kanozan

11	12	13	14	15	16	17	18	19	20	21	22	23
2463	2214	1916	1698	1494	1396	1410	1505	1675	1833	1983	2064	2079
1919	1691	1440	1208	952	826	774	802	918	1107	1269	1389	1447
1381	1252	1049	837	715	641	581	596	660	759	855	944	1028
1537	1486	1385	1233	1107	1026	967	950	974	1031	1120	1228	1335
1583	1578	1562	1507	1465	1418	1377	1357	1351	1377	1423	1473	1561
1850	1833	1789	1737	1659	1572	1510	1453	1407	1373	1367	1391	1432
1459	1442	1459	1480	1480	1463	1436	1396	1333	1250	1186	1150	1169
1227	1163	1150	1191	1241	1260	1255	1203	1098	956	822	729	715
662	554	535	574	656	745	833	858	853	803	732	623	560
793	735	724	785	876	1007	1168	1336	1485	1508	1349	1176	1089
1211	1045	915	940	1096	1277	1462	1659	1820	1901	1877	1697	1514
1331	1086	856	706	729	907	1116	1302	1415	1491	1517	1456	1357
845	504	280	122	53	82	224	445	753	989	1078	1098	1053
872	637	367	189	136	164	265	459	758	1016	1172	1240	1261
1367	1189	1008	827	654	586	608	746	928	1096	1248	1386	1494
1378	1269	1085	846	628	510	442	462	546	683	874	1069	1173
1497	1458	1420	1359	1298	1242	1226	1259	1309	1395	1551	1776	1964
2569	2546	2440	2273	2160	2092	2042	2033	2039	2063	2139	2287	2460
2767	2742	2694	2643	2594	2543	2496	2443	2422	2415	2454	2514	2576
2666	2692	2722	2746	2748	2740	2714	2678	2646	2630	2629	2638	2676
2642	2616	2612	2616	2626	2628	2622	2599	2557	2522	2498	2481	2489
2628	2629	2642	2678	2727	2795	2879	2910	2887	2818	2762	2742	2738
2797	2774	2780	2816	2875	2955	3046	3124	3173	3131	3034	2963	2943
3224	3107	3008	3055	3182	3317	3404	3442	3460	3453	3412	3343	3260
2784	2609	2479	2446	2506	2590	2689	2810	2945	3020	3010	2927	2813
2675	2525	2409	2379	2443	2596	2852	3074	3227	3263	3244	3193	3118
2655	2454	2320	2237	2249	2368	2550	2809	2996	3079	3108	3087	3027
2638	2330	2141	1998	1895	1975	2186	2496	2686	2835	2944	3024	3006
2966	2723	2467	2229	2050	2056	2156	2400	2623	2743	2826	2856	2826
2766	2612	2404	2203	2038	2008	2064	2263	2496	2670	2769	2828	2855
3102	2914	2730	2574	2436	2340	2346	2446	2574	2705	2836	2967	3081
3276	3208	3079	2958	2845	2729	2684	2725	2846	3025	3182	3308	3425
3703	3634	3533	3422	3284	3124	3000	2947	2962	3045	3204	3328	3399
3333	3302	3230	3112	2976	2803	2700	2612	2580	2605	2677	2758	2852

Unit in 0.1 mm

Gravity

February – March, 1959

Day	Hour (UT)	0	1	2	3	4	5	6	7	8	9	10
Feb.	7	2516	2470	2434	2444	2488	2569	2719	2959	3061	3083	3034
	8	3150	3109	3060	3043	3064	3130	3238	3354	3409	3417	3367
	9	3006	2867	2667	2575	2513	2510	2565	2677	2814	2914	2916
	10	2733	2698	2634	2595	2576	2590	2658	2738	2862	3021	3154
	11	3274	3255	3203	3147	3104	3081	3105	3148	3224	3296	3346
	12	3469	3418	3348	3275	3216	3196	3197	3211	3234	3252	3252
	13	3206	3190	3128	3024	2883	2761	2656	2569	2555	2571	2617
	14	2348	2316	2267	2187	2077	1950	1874	1817	1784	1765	1764
	15	1913	1997	2020	2016	1949	1852	1797	1724	1655	1619	1625
	16	1918	1927	1928	1917	1893	1852	1781	1693	1582	1484	1427
	17	1772	1803	1833	1875	1906	1897	1856	1790	1709	1623	1558
	18	2074	2099	2146	2201	2252	2288	2268	2199	2121	2024	1921
	19	2178	2194	2224	2281	2351	2418	2436	2385	2291	2202	2117
	20	2298	2255	2242	2267	2334	2413	2475	2473	2393	2247	2040
	21	2204	2148	2134	2157	2227	2328	2405	2447	2438	2384	2272
	22	2324	2249	2198	2212	2291	2386	2473	2518	2547	2517	2440
	23	2415	2326	2237	2194	2212	2303	2414	2511	2580	2587	2543
	24	2469	2364	2255	2164	2116	2185	2305	2422	2505	2549	2558
	25	2613	2520	2439	2352	2286	2294	2363	2448	2532	2613	2666
	26	2674	2575	2485	2413	2350	2313	2339	2391	2473	2552	2628
	27	2759	2669	2555	2469	2381	2321	2297	2324	2385	2453	2513
	28	2948	2944	2865	2710	2602	2540	2512	2506	2510	2540	2567
Mar.	1	2566	2551	2504	2420	2291	2132	2006	1949	1929	1935	1946
	2	2444	2470	2464	2421	2325	2226	2104	1990	1913	1847	1820
	3	2350	2403	2439	2464	2480	2449	2386	2279	2148	2010	1881
	4	2463	2503	2577	2642	2676	2698	2679	2622	2497	2277	2062
	5	2019	2056	2152	2268	2377	2448	2470	2419	2282	2061	1833
	6	1316	1209	1147	1139	1158	1181	1180	1140	1067	920	764
	7	456	340	288	311	420	559	640	689	704	682	599
	8	623	521	462	459	539	640	729	804	859	861	801
	9	1034	889	824	820	862	952	1052	1146	1186	1184	1130
	10	1474	1280	1185	1149	1152	1212	1377	1569	1690	1732	1705
	11	1468	1329	1180	1071	1039	1057	1139	1330	1503	1591	1629
	12	1722	1663	1564	1476	1427	1431	1519	1636	1713	1779	1820

Sensitivity : 3.1506 μgal/mm

Station : Tottori

11	12	13	14	15	16	17	18	19	20	21	22	23
2922	2704	2504	2361	2338	2371	2495	2723	2940	3075	3170	3212	3202
3278	3127	2868	2687	2542	2491	2524	2624	2771	2970	3095	3144	3118
2836	2703	2549	2372	2206	2127	2143	2235	2405	2575	2669	2727	2742
3165	3085	2902	2739	2576	2528	2535	2608	2810	3012	3145	3229	3273
3398	3389	3326	3255	3199	3137	3113	3121	3173	3235	3309	3387	3464
3241	3211	3167	3080	2978	2876	2803	2796	2858	2954	3066	3140	3191
2676	2717	2698	2633	2536	2479	2406	2363	2345	2339	2353	2368	2375
1778	1772	1760	1744	1712	1665	1643	1627	1644	1681	1739	1799	1853
1669	1728	1780	1804	1833	1848	1865	1864	1855	1855	1866	1883	1898
1412	1429	1464	1524	1598	1669	1702	1721	1732	1735	1740	1745	1752
1522	1531	1598	1689	1821	1922	1982	2028	2062	2076	2080	2069	2062
1830	1733	1715	1768	1877	1987	2070	2139	2172	2183	2184	2175	2172
2007	1912	1846	1868	1950	2042	2189	2364	2480	2522	2512	2455	2369
1875	1711	1624	1610	1665	1767	1949	2167	2310	2368	2382	2351	2290
2052	1814	1708	1649	1661	1754	1925	2159	2332	2421	2459	2443	2398
2302	2053	1822	1741	1705	1756	1885	2130	2362	2460	2519	2531	2488
2454	2339	2146	1968	1838	1795	1913	2135	2347	2476	2548	2576	2534
2511	2433	2315	2140	2001	1962	2006	2197	2368	2493	2599	2675	2683
2642	2561	2449	2323	2194	2086	2083	2153	2284	2427	2541	2642	2692
2678	2669	2606	2507	2425	2361	2319	2341	2396	2477	2568	2694	2782
2548	2563	2545	2497	2449	2401	2375	2377	2411	2469	2557	2675	2819
2599	2619	2626	2601	2561	2508	2441	2382	2364	2378	2437	2499	2539
1990	2066	2164	2242	2285	2309	2290	2271	2250	2259	2287	2330	2396
1834	1879	1951	2028	2146	2230	2288	2304	2297	2289	2290	2298	2316
1802	1803	1841	1919	2009	2170	2299	2403	2438	2440	2437	2433	2433
1880	1776	1748	1754	1813	1902	1981	2064	2137	2167	2150	2067	2013
1579	1374	1301	1268	1287	1360	1459	1618	1702	1728	1667	1564	1436
626	438	283	218	232	337	494	630	701	729	712	661	572
470	282	117	58	66	194	381	587	703	757	779	759	703
729	641	529	451	444	505	621	765	944	1125	1258	1264	1211
1065	962	827	701	660	716	868	1022	1182	1372	1530	1602	1576
1622	1448	1221	1037	927	909	945	1037	1173	1368	1511	1568	1561
1610	1519	1346	1196	1092	1066	1104	1265	1431	1599	1697	1743	1745
1824	1787	1735	1658	1579	1560	1592	1648	1721	1798	1892	1990	2089

Unit in 0.1 mm

Gravity

April - May, 1959

Day \ Hour (UT)		0	1	2	3	4	5	6	7	8	9	10
Apr.	18	2121	2130	2250	2335	2403	2441	2448	2428	2375	2261	2147
	19	2012	1989	2009	2118	2250	2359	2422	2429	2386	2279	2118
	20	1917	1801	1793	1885	2083	2268	2396	2464	2469	2409	2287
	21	1789	1661	1598	1639	1758	2005	2268	2388	2452	2444	2365
	22	1782	1585	1430	1400	1504	1721	1985	2150	2265	2335	2281
	23	1698	1463	1261	1134	1181	1353	1593	1832	2085	2325	2409
	24	2139	1885	1692	1543	1457	1537	1706	1917	2187	2418	2534
	25	2383	2223	2018	1771	1628	1612	1698	1893	2134	2351	2536
	26	2547	2392	2220	2025	1860	1751	1755	1876	2081	2246	2407
	27	2714	2586	2442	2284	2126	1980	1868	1879	1950	2093	2234
	28	2423	2390	2348	2260	2146	2024	1918	1883	1904	1974	2082
	29	2419	2421	2407	2362	2318	2257	2175	2099	2035	2020	2055
	30	2362	2376	2403	2417	2404	2382	2336	2279	2225	2173	2159
May	1	2366	2385	2428	2463	2496	2520	2521	2494	2460	2404	2351
	2	2278	2270	2317	2390	2456	2513	2533	2532	2490	2425	2352
	3	2156	2105	2131	2220	2345	2434	2489	2520	2514	2468	2422
	4	2086	1994	1968	2066	2197	2353	2464	2525	2535	2504	2432
	5	1924	1766	1715	1750	1851	2071	2311	2497	2613	2625	2568
	6	2091	1964	1874	1881	1968	2117	2341	2575	2678	2713	2704
	7	2350	2116	1996	1950	1988	2132	2318	2519	2729	2868	2912
	8	2599	2423	2315	2240	2243	2342	2458	2687	2947	3099	3152
	9	2955	2773	2629	2471	2411	2489	2646	2801	2975	3150	3306
	10	3171	2967	2816	2711	2642	2656	2748	2874	3070	3290	3461
	11	3467	3355	3245	3092	2945	2908	2947	3075	3217	3355	3482
	12	3579	3466	3356	3255	3127	3050	3025	3089	3193	3311	3425
	13	3595	3544	3450	3377	3295	3224	3180	3184	3257	3345	3459
	14	3747	3724	3658	3540	3444	3387	3344	3314	3322	3362	3411
	15	3671	3710	3724	3709	3648	3545	3468	3417	3398	3403	3438
	16	3739	3798	3884	3998	4016	3964	3889	3814	3760	3726	3708
	17	3958	4001	4057	4114	4180	4213	4221	4196	4150	4097	4038
	18	3997	3993	4046	4119	4217	4301	4378	4405	4328	4239	4144
	19	3946	3912	3956	4048	4155	4308	4516	4627	4658	4578	4372
	20	3980	3900	3867	3930	4124	4378	4586	4712	4749	4741	4678
	21	4070	3855	3777	3778	3908	4167	4451	4630	4757	4843	4790

Sensitivity : 2.5544 μgal/mm

Station : Aso

11	12	13	14	15	16	17	18	19	20	21	22	23
2041	1969	2015	2121	2271	2370	2453	2500	2501	2460	2371	2247	2101
1945	1818	1787	1885	2043	2242	2394	2474	2491	2478	2404	2281	2079
2116	1943	1778	1766	1874	2079	2298	2428	2479	2484	2419	2278	2065
2199	1948	1771	1708	1738	1868	2087	2299	2408	2447	2414	2295	2070
2177	2033	1842	1661	1603	1632	1773	1974	2095	2160	2164	2072	1943
2390	2259	2026	1890	1833	1823	1879	2036	2283	2448	2507	2479	2363
2587	2534	2429	2313	2227	2185	2194	2263	2371	2498	2600	2632	2532
2675	2730	2623	2482	2374	2312	2293	2308	2377	2463	2604	2683	2677
2558	2682	2725	2689	2585	2479	2413	2397	2417	2495	2659	2820	2819
2368	2452	2503	2506	2475	2433	2384	2360	2340	2349	2379	2408	2422
2232	2332	2407	2448	2480	2478	2450	2415	2394	2380	2373	2380	2394
2153	2275	2366	2429	2480	2508	2520	2504	2460	2419	2388	2374	2365
2196	2253	2330	2412	2476	2539	2587	2612	2585	2532	2464	2416	2375
2318	2315	2349	2426	2513	2606	2675	2699	2670	2592	2504	2412	2334
2284	2238	2239	2304	2396	2473	2543	2606	2637	2586	2497	2396	2267
2345	2254	2210	2246	2318	2410	2505	2599	2649	2605	2503	2392	2264
2353	2233	2124	2107	2163	2293	2396	2458	2509	2520	2459	2342	2139
2474	2318	2196	2171	2238	2348	2487	2626	2700	2722	2688	2601	2367
2645	2518	2372	2286	2282	2328	2484	2637	2734	2771	2772	2706	2586
2807	2668	2531	2450	2446	2468	2542	2670	2867	2987	3024	2989	2854
3134	3057	2946	2864	2812	2802	2834	2905	3017	3143	3282	3247	3112
3371	3328	3187	3041	2959	2921	2926	2992	3127	3278	3374	3395	3323
3524	3527	3473	3411	3365	3340	3335	3358	3398	3460	3525	3560	3537
3595	3658	3633	3574	3496	3447	3418	3410	3433	3493	3567	3646	3662
3523	3614	3665	3636	3564	3495	3447	3438	3453	3485	3544	3592	3611
3582	3694	3799	3836	3826	3758	3683	3621	3578	3575	3604	3653	3704
3499	3613	3757	3854	3899	3902	3856	3774	3681	3620	3603	3621	3641
3519	3642	3791	3917	4012	4060	4053	3986	3882	3770	3699	3666	3687
3733	3796	3917	4062	4170	4243	4269	4232	4172	4099	4043	3982	3946
4020	4047	4104	4179	4291	4474	4602	4596	4525	4339	4204	4117	4038
4074	4047	4068	4138	4249	4390	4539	4628	4601	4493	4319	4144	4021
4235	4155	4141	4160	4263	4424	4637	4750	4776	4715	4561	4270	4112
4579	4463	4360	4334	4401	4498	4625	4748	4829	4824	4738	4580	4376
4691	4577	4469	4370	4353	4426	4542	4651	4748	4807	4761	4640	4442

Unit in 0.1 mm